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THE HEAT CAPACITIES OF ORGANIC COMPOUNDS AT LOW TEMPERATURES. I. A PRECISION CALORIMETER AND THERMOSTAT FOR LOW TEMPERATURES.

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THE interest in specific heats today is due primarily to two developments in theoretical physics which took place in the first decade of the present century. One is the application of the quantum theory by Einstein and Debye [1] to the problems dealing with the thermal energy of crystals, making possible the use of specific heats for studying the motion of atoms in the crystal lattice, and the forces between them. The other is the formulation of the third law of Thermodynamics by Nernst [2] which makes specific heats of great importance in studying chemical activity. In working out the application of these principles for various substances and chemical systems the investigators in this field devoted themselves almost exclusively to the chemical elements and a few of their simpler compounds, thereby securing results which were

[1] A. Einstein, *Ann. d. Phys.* (4), **22**, 180 (1907).
P. Debye, *Ann. d. Phys.* (4), 789 (1912), vol. 39.
[2] *Nachr. kgl. Ges. Wiss. Göttingen. Math-physik. Klasse*, 1906, 1.

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an excellent confirmation of the hypotheses, but rather limited in scope.[3]

As an extension of this work the author has recently begun a survey of the specific heats of more complicated compounds, particularly the compounds of carbon. The preliminary survey which has been made indicates that the regularities of structure among these compounds constitute a unique opportunity for investigating the relation of the quantum theory to the chemical bond and the calculation of chemical activity.[4] Moreover the importance of organic chemistry to industry and medical science would itself justify any research along these lines.

However, the measurement of the specific heats of organic compounds presents certain difficulties which were not met with in the earlier work on inorganic substances. In the first place organic compounds have low heat conductivity which makes temperature measurement difficult. Secondly, many of them are corrosive so that the vessel containing them must be one which resists their chemical action. Thirdly, many of them can be obtained only in very small amounts.

The investigation described in this paper is the first step in devising apparatus suitable for making an extensive study

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[3] An account of the principal investigations in Germany can be found in the New Heat Theorem by Nernst, New York, 1927, and of work in the United States in Thermodynamics by G. N. Lewis and M. Randall, New York, 1923.

G. S. Parks and his students have made an investigation of the thermal properties of some organic compounds, especially the alcohols, from which they have drawn important deductions regarding the change of free energy in this group. See Parks, *J. A. C. S.*, **47**, 338 (1925); Parks and Kelly, *J. A. C. S.*, **47**, 2089 (1925); Parks and Nelson, *Jour. Phys. Chem.*, **32**, 61 (1928).

[4] Experimental investigations:

"The Heat Capacities and Heats of Crystallization of some Isomeric Aromatic Compounds," D. H. Andrews, George Lynn and John Johnston, *Jour. Am. Chem. Soc.*, **48**, 1274 (1926).

"The Specific Heats of Some Isomers of the Type Ortho, Meta and Para C_6H_4XY from 110° to 340° K.," Donald H. Andrews, *Jour. Am. Chem. Soc.*, **48**, 1287 (1926).

Theoretical papers:

"The Distribution of Thermal Energy in Organic Molecules," Donald H. Andrews, *Proc. Roy. Acad. Sci. Amsterdam*, **29**, 744 (1926).

"Fundamental Frequencies, Interatomic Forces and Molecular Properties," John R. Bates and Donald H. Andrews, *Proc. Nat. Acad. Sci. U. S. A.*, **14**, 124–130 (1928).

of these compounds. The calorimeter is built especially for the purpose of measuring the specific heats of such substances from about − 200° C. to room temperature with as great precision as possible. Special attention has been paid to overcoming the difficulties just mentioned, as well as sources of error present in all measurements of this type. As a test of the apparatus the specific heats of some long chain carbon compounds have been measured. Using as standards some substances as these with carefully measured heat capacities, it is planned to construct other calorimeters, much more rapid and easy to operate, with which the specific heats of a large number of other compounds can be measured by comparison with these standards.

THE APPARATUS.

The calorimeter is of the type first devised by Nernst [5] and his colleagues and improved by Gibson and Giauque [6] and by Parks.[7] It consists of a small can of gold containing the substance of which the heat capacity is to be measured. This can hangs in a vacuum chamber in order to insulate it thermally from its surroundings. A known quantity of electrical energy is passed into a heating coil in the calorimeter and the rise in temperature of calorimeter and contents observed. From this the heat capacity is calculated. The calorimeter together with the auxiliary apparatus, such as the thermostat for calibrating thermocouples are described in the following sections. The manipulation and arrangement of the various parts of the apparatus differed at times from that indicated here which represents what was found to be the most satisfactory arrangement.

The Steel Vacuum Jacket: The vessel in which the vacuum is maintained both for the calorimetric experiments and for the calibration thermostat, consists of a steel cylinder (*B*) with bottom welded in, as shown in Figs. 1 and 2. The upper edge of the inside of the cylinder is rounded off and carefully polished. This presses against a similar rounded

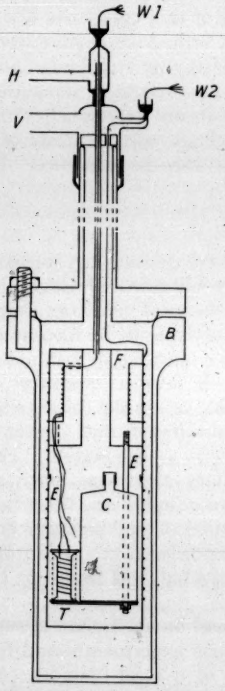
[5] Nernst, *Jour. de Physique* (4), 9, 1910; Nernst, Koref and Lindemann, *Sitzungsber. Berl. Akad.*, 1, 247 (1910). Nernst, *Ann. d. Phys.*, 4, 36, 395 (1911).

[6] Gibson and Giauque, *Jour. Am. Chem. Soc.*, 45, 93 (1923).

[7] Parks, loc. cit.

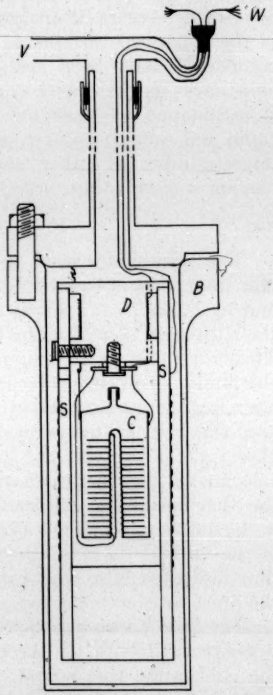
surface on the bottom of the steel cover, pressure being produced by means of twelve bolts, one of which is shown on the left side of the drawing. This proves to be a very

FIG. 1.



The Low Temperature Thermostat.

FIG. 2.



The Calorimeter, with shield and vacuum chamber.

satisfactory vacuum joint, if care is taken to keep the surface well oiled in order to prevent rust. Into the cover there is welded a steel pipe 2.5 ft. long, which terminates at the upper end in a bayonet joint. The glass tubing of the vacuum system (*v*) fits into the cavity of the joint which is made

vacuum tight with DeKhotinsky cement. The wires for heating and temperature measurements are brought out through a side arm likewise sealed with DeKhotinsky cement. A mercury diffusion pump backed with a Nelson oil pump is used to maintain the vacuum and with this system it is possible to reduce the pressure to about 10^{-5} mm.

The Low Temperature Thermostat: This was designed to provide a chamber for comparing the different temperature measuring devices. The apparatus which has been used in the past for securing constant temperature from 100° to 300° K. has nearly always employed baths of some inflammable liquid such as pentane, which is not very desirable in the neighborhood of liquid air. The apparatus described here has therefore advantage over the previous types, in this respect and in respect to the constancy of temperature.

As shown in Fig. 1, it consists of two cylinders of spun copper each closed at one end, and the open ends fitting together in a slip joint, shown just below *E*, which is made vacuum tight with low melting (60° C.) solder. This cylindrical vessel is suspended on a seamless steel tube which is hard soldered into the upper end. The tube goes up the steel pipe of the vacuum vessel and is itself supported from the top of this pipe by an adjustable collar. It passes out of the vacuum system through a DeKhotinsky cement seal (shown in heavy black) and terminates in the chamber connected to a hydrogen supply (*H*).

In the upper end of the spun copper cylinder (*E*), there is wedged a heavy cone of copper (*F*). From this is suspended by means of a small brass rod, a copper platform upon which rest the calorimeter (*C*) and platinum resistance thermometer (*T*).

The wires (*W*1) to the thermocouples on the calorimeter and to the resistance thermometer come through DeKhotinsky cement into the hydrogen chambers and then down the steel tubing into *E*, where they are wound around the block *F* several times to prevent heat leaking past, good contact being made with bakelite varnish. The wires then pass down to the resistance thermometer and calorimeter.

On the outside of the cylinder *E* there is wound a heating coil of No. 30 Constantan wire, the leads of which pass up the steel pipe and out through DeKhotinsky cement, as (*W*2).

A copper-constantan thermocouple on the outside of *E* also comes out along with the heating wires. It has the customary ice junction and is arranged so that its e.m.f. can be read on a potentiometer or balanced against the e.m.f. from a large capacity storage battery. This latter can be regulated at any value from 0 to 6,000 micro volts so that it will just balance the e.m.f. of the thermocouple when the latter is at temperatures from − 180° to 50° C. There is a sensitive Leeds and Northrup No. 2285 mirror galvanometer in series with these so that when the e.m.f.'s do not balance a beam of light is displaced. A photoelectric cell is so arranged that a movement of the beam of light activates it, and charges the grid of a three-electrode vacuum tube, which in turn operates a relay controlling the heating current through the wires wound on *E*.

The operation of the thermostat is as follows: With both the vacuum system and thermostat, filled with hydrogen through *V* and *H* respectively, the steel jacket *B* is immersed in liquid air and cooled to the desired temperature. Then the vacuum chamber is evacuated through *V*, and an appropriate cooling bath maintained around *B*. The heating current through *E* is then so regulated that the thermocouple on the outside of *E* reads the desired temperature. Its e.m.f. is then balanced against the constant e.m.f. for the storage battery, and the galvanometer so adjusted that when the temperature falls, the photoelectric cell-relay device increases the heating current about 5 per cent., until the temperature goes above the desired temperature when the operation is reversed. With this arrangement the temperature can be kept constant to 0.01° C. at any point of the range − 180° to 50° C. The thermocouples inside the hydrogen chamber where the calorimeter and resistance thermometer are placed indicate a uniformity of temperature to 0.01° C. also. This apparatus thus provides an accurate and easily adjustable thermostat over the low temperature range where the use of constant temperature baths is difficult and dangerous. The results secured with it, in comparing the constantan thermocouple and platinum resistance thermometer are described in a later section.

The Calorimeter Shield: The problem of minimizing the

error due to heat leaks from the calorimeter to its surroundings has been met in this apparatus by surrounding the calorimeter with a cylindrical shield of heavy copper tubing, shown in Fig. 2 as (*S*). It is fitted at each end with two heavy copper blocks which provide extra heat capacity. The upper block marked (*D*) is supported from the steel cover of the vacuum jacket by loops of piano wire and in turn supports the shield by means of four copper screws, one of which is shown at the lower left hand corner of the block. This block (*D*) is also cut to provide a ring-shaped cavity between it and the shield (*S*). In this cavity are wound the thermocouple and heating wires for the calorimeter, good contact being made with bakelite varnish. The wires pass out through a hold in the lower side of the block to a hard rubber plate with a ring of holes, held in place on the lower face of the block by a screw. This acts as a distributor and from it the wires are led to the calorimeter.

On the outside of the shield (*S*) there is wound a 50 ohm heating coil of nicrome ribbon. During measurements a current is passed through this, of the appropriate strength to keep the whole shield within one or two degrees of the temperature of the calorimeter. This reduces the heat leak by conduction along the wires, and by radiation and conduction through the residual gas in the system.

The calorimeter itself is suspended from the block (*D*) by means of silk threads. It is a vessel of 18 karat gold, weighs about 250 grams, has a volume of about 100 cc. and a heat capacity of about ten calories per degree. At the top there is a small copper tube through which it is filled. This tube is closed after filling with a small spun copper cap, made vacuum tight with low melting (60° C.) solder. At the bottom of the calorimeter there is a reëntrant tube or well which goes nearly to the top. This tube supports through the center a number of discs of gold, shown in the cross-section drawing as straight lines. These discs distribute the heat from the heating coil in the well throughout the material in the vessel.

THE HEATING-TEMPERATURE MEASURING SYSTEM.

The heating coil for the calorimeter is made of a piece of No. 30 constantan wire bifilarly wound in a spiral. It was

slipped in the well, from a glass rod, and bakelited to the wall, being held in contact by its own tension. From the end of the loop at the innermost part of the well, there is a No. 36 copper wire attached. This, together with one of the ends of the constantan, is brought out of the apparatus and thus serves as a thermocouple for reading the temperature inside the calorimeter. The heating current is brought in through two pieces of No. 26 copper wire attached to the constantan wires at the mouth of the well. The drop in potential across the heating coil is read by means of two wires attached to the No. 26 wires at the distributor plate on the bottom of the block *D*.

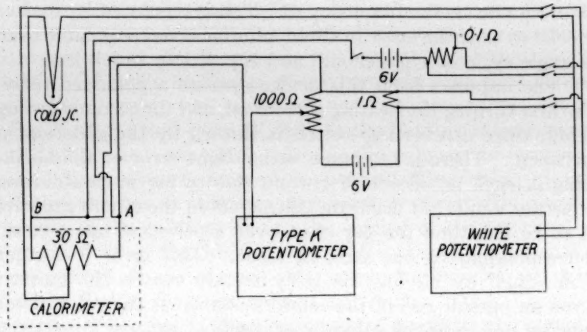
These connections are illustrated diagrammatically in Fig. 3. The No. 30 constantan wire which serves as a heating coil and thermocouple extends from *A* through the 30 ohm coil, through *B* where the lead for the heating current is taken off, to the cold junction. It is a piece of tested and calibrated wire as explained in the section on calibration.

The e.m.f. of the thermocouple is read by means of a White potentiometer made by the Leeds and Northrup Co. The most sensitive type of galvanometer was used with the scale at a distance of fifteen feet so that an absolute precision of 0.1 microvolts was secured with a sensitivity of 0.03 microvolts. The greatest care was exercised in preparing the ice in the cold junction; it was ground to mush in a porcelain mortar kept exclusively for the purpose and the optimum ratio of ice and water was maintained at all times.

The energy input in heating the calorimeter is determined by measuring the current flowing and the voltage drop across the heating coil. There is a 0.1 ohm coil, Leeds and Northrup Co., calibrated by the Bureau of Standards, placed in series with the heating coil; it is shown in the upper right hand corner of Fig. 3. The potential drop across this coil during heating is measured by means of the White potentiometer with a precision easily one part in 10,000. The potential drop across the heating coil is measured indirectly, as it is too large (six volts) to read precisely on a voltmeter or potentiometer. A six-volt battery, kept at constant temperature, sends a current through standard resistances of 1,000 ohms and one ohm, in series. The current is constant over a ten-

minute interval to one part in 10,000. This gives, for example, an e.m.f. across the 1,000 ohm coil of about 5.995 volts which is opposed to the 6 volt drop from the heating coil; the e.m.f. of .005 volt from the one ohm coil is measured on the White potentiometer, permitting an exact calculation of the larger voltage. Then during heating the difference

FIG. 3.



The heating and temperature measuring circuits.

between the potential drop across the heating coil and the above opposing e.m.f. is measured with a Leeds and Northrup Type K potentiometer. In this way the energy put into the calorimeter can be measured to one part in 5,000. This is greater precision than is necessary at present, in view of some of the uncertainties in temperature measurement; but when one wishes an accuracy greater than one part in 200, obtainable with good voltmeters, it is necessary to use the potentiometer method, and therefore it was thought well to get all the precision which could be had without undue effort.

The Timing Device: Since the energy input equals voltage × current × time, it is necessary to know the time during which the current is passed very accurately. For this reason the current is controlled by an automatic switch, which consists of a drum of hard rubber driven directly by the "minute" shaft of a Warren synchronous clock motor so

that it makes one revolution per minute. On the drum there is cut a spiral groove in which a contact point rests. There are also contacts carefully set into the groove so that when the drum turns, pulling the contacts past the point two impulses are sent out, one exactly three minutes after the other. The exact timing of the rotation of the drum is accomplished by the frequency of the current sent into the motor. This is the standard 60 cycle Philadelphia city lighting power, the frequency of which is regulated by master clocks so that the error in three minutes is never greater than a single cycle or 1/60 second, and is probably much less.

The impulses from this device operate a polarized relay, the first turning the heating current on, and the second turning it off, since a reversing switch is thrown by the observer in between. There is of course, some slight error at the beginning of each admission of current due to lag in establishing constant e.m.f. but accurate voltmeters in the circuit indicate it to be less than ten per cent. over a period of one second, corresponding to one part in 1,800. This error is further diminished by having the relay merely switch the current from an outside coil of the same resistance as the calorimeter heating coil, into the calorimeter itself.

The Method of Measuring Heat Capacity: The apparatus is assembled as shown in Fig. 2. With hydrogen in the vacuum chamber, the steel vacuum jacket (B) is immersed in liquid air until all parts of the apparatus are approximately at liquid air temperature, roughly $-180°$ C. Then the hydrogen is pumped out and a vacuum of about 10^{-5} mm. of mercury produced within the jacket. The shield (S) and the calorimeter (C) are then brought to within about 0.2° of the same temperature, and since the shield is of such large heat capacity that its temperature will remain essentially constant, even though external conditions vary, the temperature of the calorimeter will remain constant, or change very slowly (0.001° per minute) and at a regular rate. This latter temperature is read over a period of about five minutes. Then the heating current is started and allowed to flow for exactly three minutes. This raises the temperature about 2°. During this interval the energy input is measured as explained above. Then readings are taken at five minute intervals

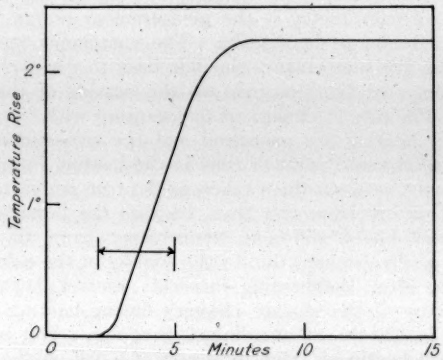
for about forty minutes. With the materials studied in these experiments it was found that temperature equilibrium was attained after about twenty minutes. The calorimeter being above the temperature of its surroundings will cool at the rate of about 0.002° per minute. The method of estimating the rise in temperature is explained in the following section.

The Measurement of Temperature: Undoubtedly the chief problem of calorimetry is the measurement of temperature and its relation to heat leaks. The customary method of measuring the temperature rise has been to use a resistance thermometer or thermocouple on the outside of the calorimeter. The rate of change of temperature with time before and after heating are measured and the two curves extrapolated to the mid point of time in the heating interval and the distance between them taken as the true rise in temperature. This involves error first, because the outside of the calorimeter has a different temperature from the inside, because of the gradient due to the cooling of the calorimeter especially after the heating interval; second, because the temperature of the surface changes during heating so that the heat loss to the surroundings is irregular. This is especially true if heating is done by means of a coil on the outside of the calorimeter.

In this apparatus this error has been minimized by placing both heating coil and thermocouple in the interior of the calorimeter. Moreover as the actual temperature of the surface of the calorimeter during heating has been observed by means of a thermocouple soldered to the gold surface, it is found that the rate of change of temperature of the calorimeter is proportional to the temperature difference between the surface and the interior wall of the shield (S), as Newton's law of cooling would lead us to expect. Moreover, observations of the surface temperature of the calorimeter during a number of runs have shown that the rise in temperature of the surface always follows the same general shape of curve. A typical curve is shown in Fig. 4. From this we find that the net cooling effect actually produced is the same *as if* the surface had changed temperature at its preheating rate for the first two minutes of heating, and then suddenly jumped to its post heating value and continued

along the extrapolation of the post heating curve for the last minute of the heating interval. Therefore if we extrapolate the preheating and post heating temperature curves to the time when two-thirds of the heating interval has elapsed, the difference between the two curves will be the true rise

FIG. 4.



Surface Temperature of the Calorimeter, before, during, and after heating. The heating interval is indicated by the arrows.

due to the energy passed in. This is the procedure that has been followed in calculating the results presented in the later sections.

THE CALIBRATION OF THE THERMOCOUPLES.

The temperature scale for this investigation is based upon the readings of a platinum resistance thermometer which was constructed for the purpose. The wire which conforms to the Bureau of Standards specifications, and was furnished by Baker and Co., is wound on two crossed pieces of mica in the usual fashion. These are supported between two bakelite discs—one at the top and one at the bottom—the whole being surrounded by a cylindrical cage of copper gauze. The thermometer is shown in Fig. 1; the dotted lines represent the gauze cage. In this way the hydrogen has free access to the platinum wire. Varying the current

through the thermometer fourfold changes the temperature less than 0.01° C. so that it seems certain the thermometer is at the temperature of the other objects in the thermostat.

TABLE I.

Deviations of e.m.f. of Bartol Laboratory Constantan Wire from I.C.T. values.

Temperature of Comparison.	Deviation Observed	Value Read from Smooth Curve through Deviations.
−171.54° C.	2.80° C.	2.80° C.
144.88	2.07	2.07
122.83	1.52	1.57
113.73	1.45	1.41
101.90	1.17	1.18
90.39	0.99	0.99
87.32	0.94	0.94
64.52	0.65	0.64
40.94	0.36	0.37

The fundamental constants of the thermometer were determined at the temperatures of melting ice, melting mercury, and boiling oxygen, the constancy of temperature in the last case indicating the oxygen to be about 99.95 per cent. pure. The resistance conformed to Henning's tables.[8] With the help of the thermostat shown in Fig. 3 the thermometer was compared with the copper constantan thermocouples at ten different temperatures between 0° and − 180° C. and the deviations of the thermocouple readings from Adams' table [9] were plotted and gave a smooth curve as shown in Table I. These deviations are due to the variation in composition of different lots of constantan wire. The wire used for this work, while not giving as high an e.m.f. as Adams', was very uniform in composition as shown by passing it through liquid air, and observing the resultant e.m.f. As the result of these observations it appears that the absolute values of the temperature readings are accurate to 0.02° C. and that the relative error in measuring a rise in temperature of about 2° is about 0.003° at − 180° C. and 0.001° at room temperature. In order to make use of this accuracy in measuring rise of temperature it will be necessary to get an e.m.f.-temperature table for thermo-couples extended to thousandths of a degree instead of hundredths as Adams'

[8] Landolt and Bornstein Tabellen. Fifth Edition.
[9] International Critical Tables 1926.

table. Such a table is being worked on at present and when it is finished, it is hoped that the full accuracy of the calorimeter will be available.

TABLE II.

Heat Capacity of the Calorimeter.

Mean Temperature.	Heat Capacity Calories per Degree.
−154.5° C.	10.89
−149.3	11.00
−145.1	11.04
−139.1	11.23
− 98.8	11.80
− 62.9	12.12
− 45.5	12.40

TABLE III.

Heat Capacity of n-heptaldehyde.

$CH_3.CH_2.CH_2.CH_2.CH_2.CH_2.CHO.$

Mean Temperature.	Molal Heat Capacity Calories per Degree.	Specific Heat Calories per Degree.
−167.57° C.	29.40	0.258
−165.53	30.02	0.263
−127.00	39.30	0.344
−125.68	39.49	0.346
− 81.73	49.73	0.436
− 80.32	49.19	0.431
− 56.4 *	79.80	0.699
− 55.3 *	103.50	0.907

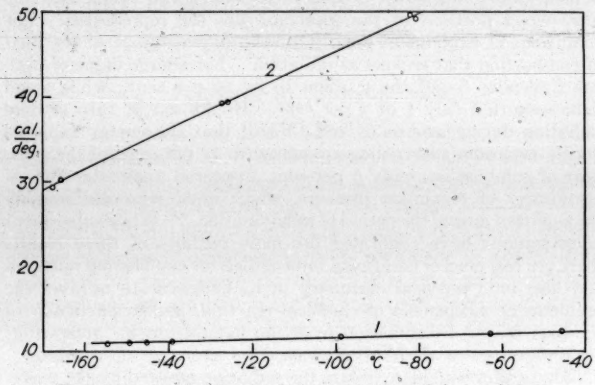
* Partial melting taking place.

Experimental Behavior: As an example of the results which can be secured with the calorimeter there are given in Tables II and III, the heat capacities for the calorimeter itself and for n-heptaldehyde. The other heat capacities measured with the calorimeter will be presented in Part II of this paper together with a discussion of their theoretical significance.

The average deviation from the best smooth curve is 0.39 per cent. in the case of heptaldehyde and 0.18 per cent. for the calorimeter itself. These errors are of the same order of magnitude as the errors in making temperature measurement a good part of which is due to the uncertainty in using the thermocouple e.m.f. tables from the International Critical Tables. The author, therefore, plans to make measurements for an e.m.f. temperature table which will be accurate to about 0.002° C., at least for measuring the

temperature rise. This will be used for calculating the other specific heat measurements.

FIG. 5.



The heat capacity (1) of the gold calorimeter, (2) of one mol of n-heptaldehyde.

Considering the accuracy with which the other factors have been measured, these measurements should serve as a good standard for further investigations when the temperature scale can be accurately established.

A Method of Measuring the Radiant Heat Emitted during Gaseous Explosions. C. H. JOHNSON. (*Phil. Mag.*, Feb., 1926.) A considerable part of the heat of combustion is radiated from flames. Infra-red waves predominate though the visible and the ultra-violet portions of the spectrum also are represented. The conditions of experiment greatly affect the percentage of the heat of combustion that escapes as radiation. For a large flame of coal-gas Callendar found the fraction to be 16 per cent., while small flames emitted only 2 or 3 per cent. Hopkinson in 1910 studied radiation during explosions and "found that the energy radiated during explosion and cooling amounted to 22 per cent. of the gross heat of combustion; only 3 per cent. appeared up to the time of attainment of maximum pressure, which must represent roughly that emitted during the period of inflammation." While subsequent investigations have confirmed the main outlines of these results there is a real need of additional information for engineering purposes and also for "physical chemistry in its endeavor to unravel the problems of mechanism of chemical reaction, and in particular of the part played by radiation from the flame front in 'activating' the unburnt gases ahead of the wave."

The author sought to isolate the radiation emitted by the wave-front from that coming out of the hot products of combustion behind it. For this purpose he used a long cylindrical bomb in which the burnt gases cool quickly and thus soon drop out of consideration as radiators. His explosive mixture consisted of carbon monoxide and oxygen in the proportions 2 : 1. The per cent. of the gross heat of combustion radiated during explosion was for the dry mixture 8.6, for the wet mixture 2.3, and for the dried gas containing 1 per cent. by volume of CCl_4, 9.5. "The effect of water, and incidentally of other catalysts, upon the emission of infra-red radiation from the wave-front in explosions of carbon monoxide and oxygen has proved to be of considerable magnitude. In particular, an additional 7 per cent. of the gross heat of combustion was radiated from a dried gas mixture in excess of that emitted in the presence of 1.9 per cent. of water-vapor."

G. F. S.

THE REFLECTION OF HYDROGEN ATOMS FROM CRYSTALS.

BY

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BARTOL RESEARCH FOUNDATION
Communication No. 28.

THE distribution in angle of molecules reflected from a surface was first investigated by R. W. Wood [1] who found that a unidirectional beam of mercury atoms was diffusely reflected from a polished glass surface. Previously in the study of the flow of gases through tubes and similar phenomena, the hypothesis of diffuse reflection had been found satisfactory in most cases for explaining the observed transfer of momentum from a gas to a surface,[2] but in a few instances it was thought that some specular reflection must have existed. More recently Ellett and Olson,[3] using the direct method of molecular beams, have shown that mercury and cadmium atoms are specularly reflected in a considerable amount from a cleavage surface of a heated crystal of rock salt.

Somewhat over a year ago the writer began a study of the reflection of atomic hydrogen from crystals. The first experiments,[4] in which a many crystal surface of ice was used, gave an indication that atoms, like electrons,[5] could be regarded as waves capable of being diffracted from a crystal grating. A continuation of the work with ice, however, revealed the fact that the hydrogen beams which were at first attributed to diffraction by the ice crystals were really of quite a different character and had to be ascribed to some irregularity in the apparatus. The actual reflection in this case was probably nothing more than diffuse. The

[1] R. W. Wood, *Phil. Mag.*, 30, 300 (1913).

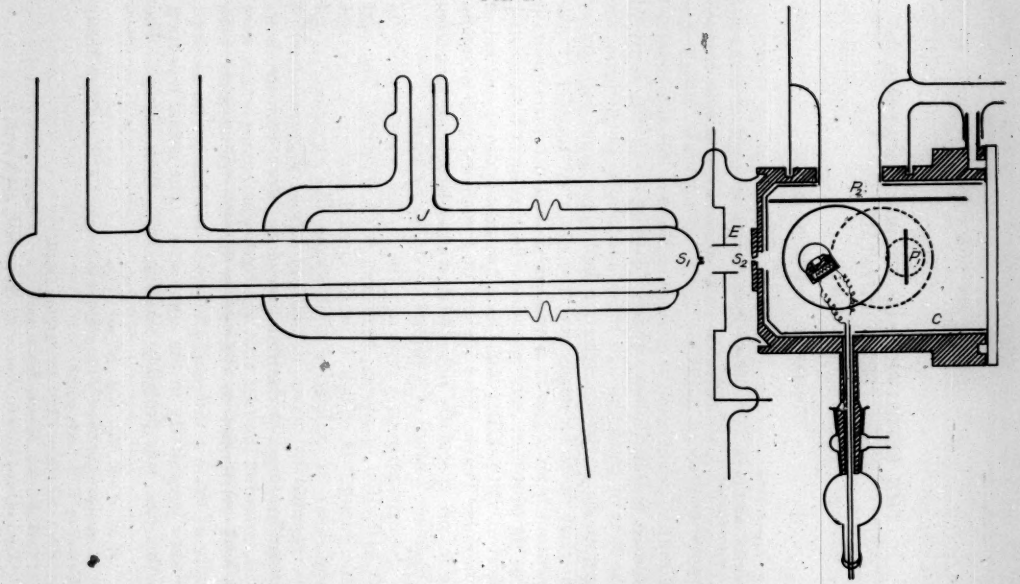
[2] A complete discussion of this evidence is contained in "The Kinetic Theory of Gases" by L. B. Loeb, p. 308.

[3] Ellett and Olson, *Phys. Rev.*, 31, 643 (1928).

[4] T. H. Johnson, *Nature*, Aug. 6, 1927.

[5] Davisson and Germer, *Jour. of the Frank. Inst.*, April, 1928.

FIG. 1.



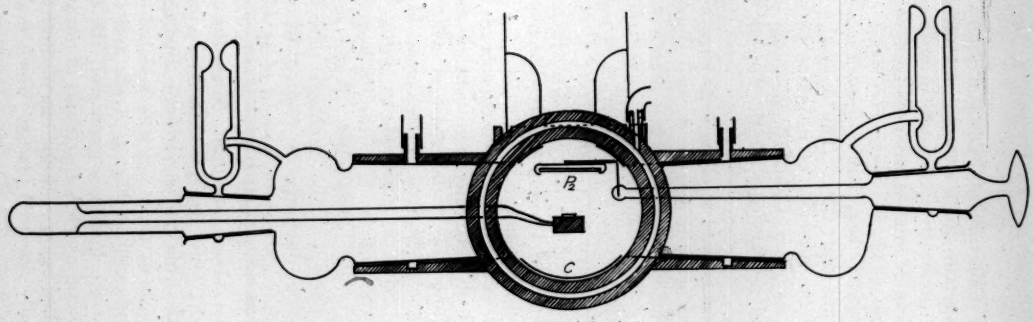
Side view of the experimental arrangements.

study of the reflection of hydrogen atoms has now been extended to certain single crystals and although the results are still only qualitative, they are in most respects definite and of considerable interest from the point of view of existing theories. The work is being continued with improved technique and it is hoped that quantitative results will be forth coming in a short time. The ultimate goal is a complete knowledge of the intensity of reflection of hydrogen atoms from crystals as a function of the direction of incidence and reflection, and a knowledge of the factors which influence this intensity.

The apparatus used in these experiments is essentially a device for producing a sharply defined ribbon-like beam of hydrogen atoms in a space which is otherwise comparatively free from gas. This beam is allowed to fall upon the reflecting surface and the intensity of reflection is measured by the use of a plate coated with a thin layer of molybdenum trioxide. The parts of the oxide surface which are exposed to the hydrogen atoms become visibly darkened by reduction to metallic molybdenum.

The source of the atomic hydrogen beam is a narrow slit S_1 in the wall of along discharge tube of the type known as a Wood tube, the central part of which is shown as a part of the experimental arrangement in Fig. 1. This part of the tube is designed to bring the discharge right up to the slit so that the hydrogen in the tube near the slit is well dissociated. Water in the jacket J prevents this portion of the discharge tube from becoming overheated. The discharge is excited by a 10,000 volt transformer which produces a current of 45 milliamps. under the pressure conditions which customarily exist in the discharge tube, i.e. about 0.15 mm. Since the gas continually escapes through S_1 it is also replenished by a variable "potentiometer" leak from an electrolytic hydrogen generator. This leak consists of three properly selected capillary tubes arranged as indicated in Fig. 3, A, B, and C being joined respectively to the hydrogen generator, the discharge tube and to an oil pump which is also a part of one of the pumping systems described below. Inside one of these capillary tubes is a magnetically operated plunger which makes possible a

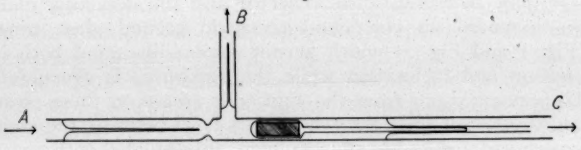
FIG. 2.



End view of experimental chamber.

variation of the resistance of this tube and consequently the pressure in the discharge. The arrangement now in use permits a variation of the discharge pressure from .03 mm. to .3 mm. and with the plunger once set, the pressure remains constant to within one or two per cent. over a period of several hours. In order that the hydrogen atoms may not recombine before leaving the discharge tube, it is necessary

FIG. 3.



Adjustable "Potentiometer" inflow leak.
A, hydrogen generator, *B*, discharge tube, *C*, oil pump.

to avoid having any metal inside the tube. Consequently the slit S_1 which is .13 mm. wide and 6 mm. long was formed in the glass itself. This was done by pressing the glass, while hot, down upon a thin strip of copper which was subsequently dissolved out with nitric and hydrofluoric acids.

Opposite and parallel to S_1 and at a distance of 1.5 cms, is a second slit S_2 having the same dimensions as S_1. This slit is in the wall of a cylindrical brass box which is waxed to the glass parts already described. In this box the reflection and the detection of the beam takes place. The region between the two slits is evacuated by means of a four stage all-steel Gaede diffusion pump operating through a short tube of large diameter and a special low resistance mercury vapor trap.[6] This pumping system is very satisfactory in reducing the pressure between the slits to the point where scattering by collisions is inappreciable and practically all of the atoms passing through S_2 come directly from S_1. In fact, the background on a plate exposed to the direct beam is of the order of one three hundredth of the intensity of the central part of the beam and falls off rapidly with the distance from the beam. The pressure between the slits as measured by a

[6] T. H. Johnson, Jour. Franklin Inst. Jan. 1928 a Mercury Vapor Trap of Low Resistance.

McCleod gauge is usually between 10^{-4} and 10^{-5} mm. To be sure that none of the effects observed are due to ions, these can be swept out by an electric field applied between the electrodes *E*. The brass box, the end of which is closed by a glass plate is evacuated by another independent pumping system consisting of a Holweck molecular pump connected by a short glass tube of large diameter and backed by an oil pump. The measured pressure in this chamber is usually less than 10^{-5} mm. The reflector and the detecting plate are mounted on compound eccentric ground glass cones (Fig. 1 and Fig. 2) which permit some adjustment both in position and inclination while the apparatus is evacuated. To prevent vapor from the stop cock grease on these cones and wax vapor from the other joints from entering the main experimental chamber all such joints are provided with guard rings connected to liquid air traps, and are greased or waxed only on the outside of these guard rings. The way in which these guard rings are arranged is clearly seen in Fig. 1 and Fig. 2. It was found that this precaution was important because a layer of grease on the interior surface of the brass box makes this surface reflecting to the atoms without their recombination and the detecting plate soon becomes generally darkened. In order to have, always, a clean interior surface a nickel cylinder *C* which is coated with platinum black is fitted into the box and this can be removed occasionally and recoated. It has been found that a fresh surface of platinum black is completely effective in recombining the atoms which strike it, and if it is protected from grease long exposures produce little general darkening of the detecting plate and a renewal of the platinum black surface is necessary only after many hours. This, however, is not true if liquid air is not applied to the traps connected to the guard rings.

Several different crystals have been tried as reflecting surfaces. In each case the crystal was mounted in a copper holder, one design of which is represented in some detail in Fig. 1. This holder has within it a resistance heating element by means of which the crystal can be raised to any desired temperature. For this reason the holder is mounted on two quartz rods which are joined by a graded seal to the glass extension of the inner ground cone. The crystal holder is

adjusted in position so that the surface of the crystal is on the axis of this cone. Thus rotation about this cone produces no displacement of the crystal with respect to the beam. The axes of the cones and the surface of the crystal are parallel to the slits. The distance from S_2 to the crystal is 1.8 cms. In some experiments a thermocouple was placed beneath the crystal but since it was impossible to know the temperature of the surface of the crystal from the reading of the thermocouple this has not been generally used and in the work which has been done the temperature was not accurately known.

The detecting plate is placed in either one of the two positions P_1 or P_2 shown in Fig. 1. These plates are of glass smoked with the white trioxide of molybdenum produced by burning thin strips of molybdenum in an oxygen-gas flame. For the formation of a uniform smoke deposit a special chimney has been found of great advantage. This chimney consists of a tube fitted with several wire gauzes. An air jet produces a thorough mixing of the smoke with the air so that above the chimney a uniform cloud of white smoke arises which deposits out on the glass plate which is held above it. The darkening of the oxide surface, due to its reduction by atomic hydrogen, can be examined either visually or it can be analysed with a densitometer. It has been found that the density as measured by the densitometer is proportional to the number of atoms which have struck the plate. There is some difficulty, however, in getting a sufficiently uniform smoke deposit to make such density measurements strictly reliable without a preliminary analysis of the unexposed plate. An accurate correlation between the position on the plate and the angle of reflection can be made by the measurement of linear distances between the plate and the crystal, and on the plate.

All of the crystals which have been investigated reflect the hydrogen atoms diffusely if the temperature of the surface is high enough. These include cleavage surfaces of calcite, sylvite, and rock salt and natural crystal faces of quartz. The intensity of the diffuse reflection depends markedly upon the temperatures of the crystal and in a way which is characteristic of the particular crystal. Sylvite must

be at a very much higher temperature than rock salt to reflect diffusely with the same intensity, whereas quartz and calcite must be at a temperature somewhere between these other two. It seems that this type of reflection is to be explained, at least in part, as an adsorption and a reevaporation of the hydrogen atoms from the surface. The mean life in the adsorbed state of an atom is to be thought of as depending upon the temperature, and as determining the amount of reevaporation in the atomic state. If the mean life is long, the probability of recombination at the surface will be high and relatively few will escape as atoms, whereas with a short mean life the probability of recombination will be small and many will escape as atoms. We naturally think of the mean life as being a function of a/kT[7] where a is the energy of adsorption of a hydrogen atom on the crystal surface, k the Boltzman constant and T the absolute temperature of the surface.

In addition to the above described diffuse reflection, a cleavage surface of rock salt also reflects specularly. With the detecting plate at a distance of 1 cm. from the crystal the specular beam can be exposed in thirty minutes. From a comparison of the intensities of the specularly reflected beam and of the primary beam it has been found that near grazing as much as 10 per cent. of the incident atoms are reflected specularly if the temperature of the crystal is just under its sublimation point, i.e. in the neighborhood of 400° C. Since the crystal is also a good reflector of the beam of light which comes from the discharge and is collimated by the slit system it has been possible to compare the direction of the specularly reflected atom beam and the specularly reflected light beam in the region near grazing. These have been found to exactly coincide. Since other substances which are good reflectors of light seem not to reflect hydrogen atoms, it is certain that the light beam has nothing to do with the observed effects.

The intensity of the specular beam from rock salt depends upon the angle of incidence and on the temperature of the crystal. An upper limit to the temperature range over which observations are possible is placed at the point where a deposit of salt begins to form over the surface of the detecting

[7] For example the theory of Frenkel Zs. für Phys. 26, 117.

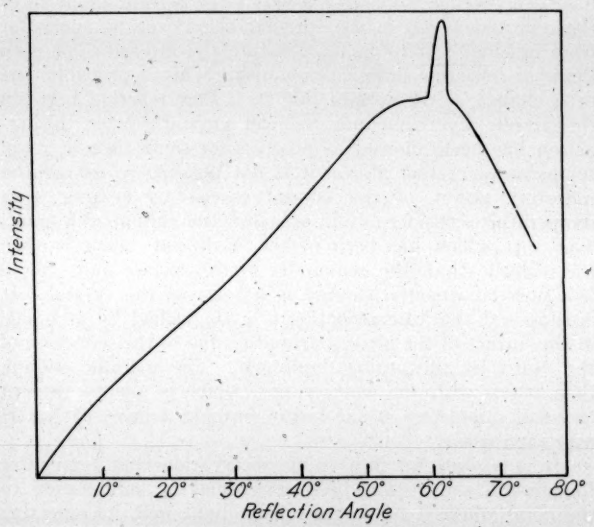
plate due to the sublimation of the crystal. This temperature is thought to be somewhere near 400° C., or perhaps a little lower. At this temperature the intensity near grazing is perhaps twice that at 30° and twenty times that at 60° from grazing. These ratios have been determined only approximately by visual comparison of double exposures. At lower temperatures the specular beams have more nearly the same intensity for all angles of incidence. Furthermore the diffuse background becomes less intense at low temperatures and it has been possible to observe a very large percentage of all of the reflected atoms in the specular beam even at angles far from grazing. At room temperature the intensities of both kinds of reflection practically vanish. This is probably due to a change of the surface due to a slow reaction between the atomic hydrogen and the salt crystal. After this reaction has been allowed to progress for some time at room temperature or just above, it is not possible to restore the reflecting power of the crystal except by heating to a temperature considerably in excess of the sublimation point. The area which has been in the hydrogen beam is then less volatile than the remainder of the surface and after a few such treatments a hump is left across the crystal. It is supposed that the reflection is extinguished by a change in the surface of the crystal primarily due to the reduction of the NaCl by the atomic hydrogen. The metallic sodium then reacts with the water vapor, which is always present in small quantities in the beam, forming a layer of NaOH over the surface.

It is perhaps an interesting observation that even after the crystal surface has been roughened by sublimation to the point where it no longer reflects light well, its reflecting power for atoms is but slightly impaired, and the specular beam still remains perfectly sharp. This must mean that the crystal surface evaporates in such a way as to leave small areas of the crystal planes intact.

A concrete idea of the relative importance of the specular and diffuse reflection is gained from the densitometer record of the reflection at 60° from grazing incidence which is reproduced in Fig. 4. The temperature of the crystal in this case was just below the sublimation point and the specular

beam was less intense compared with the background than could have been realized at lower temperatures, as has been stated above. Since no very great care has yet been taken to produce a uniform coating of oxide it is impossible to draw any very definite conclusions from the densitometer record, in regard to the distribution in angle of the diffusely reflected atoms but it seems quite certain that the directions near the specular beam are most probable.

FIG. 4.



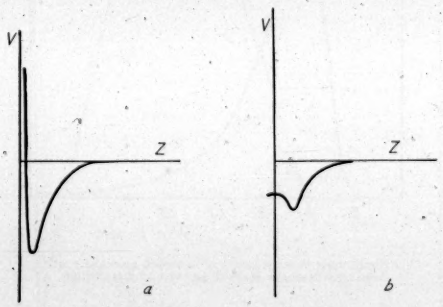
The intensity of reflection as a function of the angle of reflection as measured by the densitometer. The angle of incidence was 60° from grazing.

From the standpoint of the old mechanics the forces between the atom and the crystal may be of three types.[8] (*A*) According to the old Bohr picture, the hydrogen atom is an electric doublet. The field of the doublet produces in the dielectric crystal an induced polarisation and the inter-

[8] Lenard-Jones, *Trans. Farad. Soc.*, Feb. 1928.

action between the electric moment of the atom and this polarisation is a force of attraction. (*B*) The surface of the crystal is to be thought of as being made up of alternately positive and negative ions. The field due to these ions produces an induced polarisation of the atom and the forces due to this cause are again attractive. (*C*) Only when the atom comes very close to one of the lattice points does it experience a repulsive force and this force is ordinarily supposed to vary as about the inverse tenth power of the distance. In this regard, then, the lattice points behave very nearly as hard elastic spheres and the repulsive forces should be perfectly rough for a particle as small as the hydrogen atom. Since it is only possible to understand specular reflection of particles if there exist repulsive forces which are smooth and act normally to the surface, the old mechanics seems to be inadequate for describing this phenomenon.

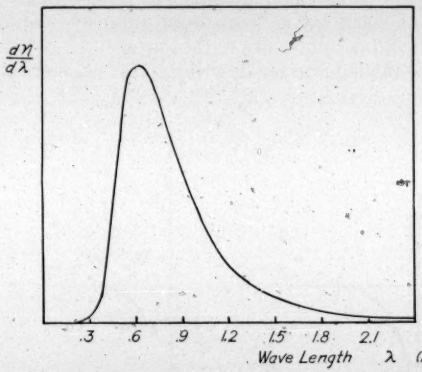
FIG. 5.



From the standpoint of the wave mechanics the atom beam is to be regarded as a set of plane waves propagated in the direction of the beam with a phase velocity $w = c^2/v$. The property of the crystal which is of interest for the reflection of waves is the potential distribution in the region of the crystal face. With this potential function known it is at least ideally possible to calculate the amplitude of the reflected wave as a function of the velocity of the incident atom and the angle of incidence and reflection. The observed

reflection may therefore be regarded as a proof of an assumed potential function. If we define the potential as the work which must be done to bring the hydrogen atom up from infinity we may expect the potential distribution along a normal drawn through one of the lattice points to be represented by a curve such as Fig. 5, *a*, and along some other intermediate normal by a curve such as Fig. 5, *b*. The wave problem with such a potential distribution is undoubtedly one of great difficulty but it is possible to predict some properties of the solution because of the close analogy with classical optics. In the first place there should be specular

FIG. 6.

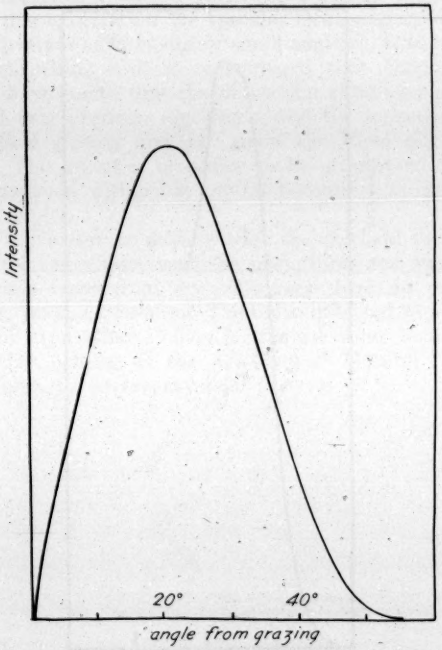


The distribution in wave-length of hydrogen atoms at 200° C. Calculated from the Maxwellian velocity distribution.

reflection if the potential irregularities are evenly spaced even though the spacing is of the same magnitude as the wave length. Secondly, the intensity of specular reflection should be greater near grazing than near normal incidence. Thirdly, there should be interference maxima in directions other than that of the specular beam. And fourthly, the reflection should be more intense for the longer wave lengths (slower atoms). The wave theory, then, is in qualitative agreement with the experiments in regard to the first two predictions. The fourth prediction has not yet been tested

experimentally. It will be shown that the absence of other diffraction maxima in the intensity distribution represented in Fig. 4 can be attributed to the velocity distribution in the atom beam and the dispersion which exists in such

FIG. 7.



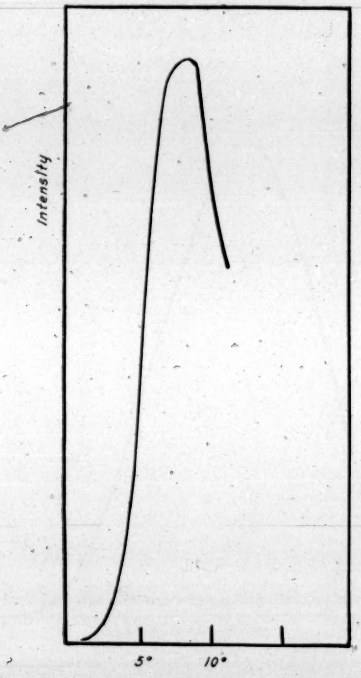
The distribution of intensity in the first order diffraction beam from the surface lattice of rock salt at 60° from grazing incidence, calculated from the wave-length distribution of Fig. 7.

diffraction beams. If we assume the velocity distribution in the discharge tube is Maxwellian, then the corresponding distribution in wave lengths ($\lambda = h/mv$) of the atoms in the beam will be given by

$$dN = (Ae^{-\beta/\lambda^2}d\lambda)/\lambda^5,$$

where β is a constant depending upon the temperature and the mass of the atom. At 200°C., the probable discharge tube temperature, this distribution has a maximum at 0.7 Å. and is represented graphically in Fig. 6. The corre-

FIG. 8.



Calculated intensity of the specular beam assuming Bragg interference.

sponding distribution in angle of the first order diffraction beam after reflection from a surface grating of the spacing of the rock salt crystal (d = 2.56 Å.) at 60° from grazing incidence is represented in Fig. 7. It is seen that this beam is spread over about 50° and its identification, at least in the present stage of the work, is quite unthinkable.

Diffraction effects due to the volume lattice have likewise not been found. If we assume that only those atoms are specularly reflected whose wave-length satisfies the Bragg formula $n\lambda = 2d \sin \theta$ the intensity of the specular beam should vary with the angle, owing to the distribution in wave-lengths, in a manner represented in Fig. 8. Contrary very to this expectation the specular beam undergoes only a slight variation of intensity of small angles. This, however, is not surprising if it is remembered that Davisson and Germer have found that the diffraction effects for electrons reflected near grazing are almost entirely dependent upon the surface grating and not upon the three dimensional lattice. This result is of course to be interpreted to mean that absorption within the crystal becomes very important at small angles.

It is a pleasure to acknowledge the excellent facilities of the Bartol Laboratory and the inspiration and suggestions which have come from my colleagues there, in particular from Dr. W. F. G. Swann. I am also indebted to Professor Barnes of Bryn Mawr College for the use of his densitometer and to Dr. Gordon of the Academy of Natural Sciences, Philadelphia, for several crystals.

The Fluorescent Spectrum of Sodium Vapor in the Vicinity of the D Lines. R. W. WOOD AND E. L. KINSEY. (*Phys. Rev.*, May, 1928.) The investigators sought to find whether fluorescing sodium vapor could be made to emit the D lines under the excitation of monochromatic radiation of any wave-length other than that of these lines themselves. The light of a carbon arc passed to a monochromator from which a beam, embracing a range of wave-lengths equal to 50 Ångstrom units, was directed upon the sodium vapor. Repeated failures were finally followed by success when hydrogen, air or nitrogen were introduced into the fluorescing vapor. "As before the D lines, excited by light in which their wave-lengths were absent, attained their maximum intensity when the pressure was about 3 mm. disappearing at higher or lower pressures, i.e. at 2 and 4 mm. By turning the prisms in the monochromator, the wave-length of the exciting radiations could be altered. It was found that as the exciting beam moved into the blue region from the shorter wave-lengths the D lines appeared feebly, growing stronger until the wave-length of the exciting light lay between 5,100 Å. and 5,250 Å. in the green where they reached their maximum intensity. As the wave-length was increased further the D lines diminished in intensity and finally disappeared until the yellow region was reached where they were again excited by radiation of their own wave-length." Atomic sodium does not show any absorption in the region between the D lines and 3,302 Å. The radiation in this part of the spectrum must therefore be absorbed by sodium in molecular form. "The excited molecule may then cause the D line emission by collisions of the second kind with atoms, or by dissociating, either spontaneously or as a result of collisions with a foreign gas, into a normal and an excited atom."

G. F. S.

MAGNETIC PROPERTIES OF PERMINVAR.

BY

G. W. ELMEN, M.A.

IN 1921 the writer was investigating the magnetic properties of a series of permalloys [1] to which a few per cent. of a third metal was added to the nickel and iron. One of these alloys contained cobalt. Magnetic measurements indicated that up to moderate field strengths the permeability of this nickel, cobalt, iron alloy was remarkably constant. The constancy was materially better than for soft iron, notwithstanding the fact that the initial permeability was several times higher. This was unusual, as small permeability variation ordinarily is found only in materials with low permeability. Measurements of other magnetic properties were equally surprising. When the hysteresis loop was traced for a cycle which carried the flux density up to a few thousand gauss, it was found to have an extraordinary form in that it was sharply constricted in the middle. These and other differences which were observed indicated that this alloy was a new type of magnetic material in which the magnetic properties were fundamentally different from those of previously known materials.

This discovery aroused a great deal of interest for it was recognized that magnetic materials possessing these properties were of great scientific and technical importance. In order to develop the possibilities which this alloy suggested, an exploration of the whole field of the iron-nickel-cobalt series was undertaken. For it was, of course, apparent that the alloy which had aroused our interest must be one of a group of compositions which possessed similar properties in a greater or less degree. In this survey, alloys varying in 10 per cent. steps in composition and including the whole range of the ternary series of these metals were made up and their magnetic properties measured.

[1] Arnold & Elmen, JOUR. OF FRANK. INST., May, 1923, p. 621.

These measurements showed the range of compositions which shared in such unusual magnetic properties, and indicated that heat treatment was an important factor in the development of these properties. A large number of alloys have been made up in this range, for which the variations in composition were evenly distributed but much smaller than for the initial survey. From these alloys a few were selected which appeared to be specially suited for magnetic uses in electrical communication circuits. Our experience with these alloys has been that when good grades of commercial materials are used, the castings are readily reduced mechanically to the desired dimensions, and the magnetic properties from different castings of the same composition are quite uniform.

We felt that these alloys were so unique as regards magnetic quality that they should be grouped in a class under a common name which should readily distinguish them from other materials. We have chosen "perminvar" as the name for alloys in the iron-cobalt-nickel series, which are characterized, when properly heat treated, by constancy of permeability for a considerable range of the lower part of the magnetization curve, by small hysteresis loss throughout the same range of flux densities, and by a hysteresis loop constricted at the origin for medium flux densities.

This paper describes the magnetic properties of the perminvar group of alloys. Results are given for several alloys selected to show the variation in magnetic properties when the proportions of the constituent metals are varied over a wide range. Detailed measurements under a variety of magnetic conditions and heat treatments are recorded for the composition 45 per cent. nickel, 25 per cent. cobalt and 30 per cent. iron. This composition is a typical one and was chosen early in our experimental work as specially suitable for commercial uses, for it had, in addition to the unusual properties in which we were most interested, a fairly high initial permeability.

PREPARATION OF ALLOYS.

The alloys were cast from the best available commercial materials. Armco iron, electrolytic nickel and commercial

cobalt were melted together in the desired proportions in a silica crucible in a high frequency induction furnace. Before pouring, one-half of one per cent. of metallic manganese was added to the molten metal. Part of this manganese deoxidized the metal and went into the slag, and the remainder, usually about one-half of the added amount, remained in the alloy. The alloys also contained small amounts of carbon (less than .03 per cent.), silicon (less than .1 per cent.) and traces of sulphur and phosphorus. The alloys were cast into bars 18 in. long and 3/4 in. in diameter. The bars were rolled or swedged into 1/4 in. rods and drawn from that size to .062 in. diameter wire. This wire was flattened and trimmed into tape 1/8 in. × .006 in. The material was annealed several times in the reduction process, for the cold working hardened the alloys rapidly and made them difficult to work.

To prepare the tape for heat treatment and subsequent magnetic measurements, about 30 ft. of it was wound spirally into a ring of 3 in. inside diameter, the ends being spot welded to the adjacent turns. Care was taken to wind the rings loosely to prevent the turns of tape from sticking during annealing.

A number of such rings were packed in a nichrome pot. Some iron dust was usually placed in the pot to take up the oxygen and thus prevent the oxidation of the rings. Further protection was secured by luting the joint between the pot and its cover. The pot was placed in an electrical resistance furnace, the temperature of the furnace raised to 1000° C. and held at that temperature for one hour. The current was then turned off and the pot cooled with the furnace. Ten hours were required for the furnace to cool to the temperature of the room. Between 700° C. and 400° C. the rate of cooling was approximately 1.5° per minute.

Three rings of each composition were always annealed together. One of these rings received no further heat treatment. The second ring was placed for 15 minutes in a furnace held at 600° C., then removed and cooled rapidly on a copper plate. In some cases, the third ring was heated 24 hours at 425° C.

In the discussions and in the figures and tables, the rings

which received the first heat treatment only are referred to as "annealed," those reheated to 600° C. and rapidly cooled as "air quenched," and those held for a long time at 425° C. as "baked."

MAGNETIC MEASUREMENTS.

Permeabilities at low magnetizing forces were measured on unwound rings with an inductance bridge, and an a.c. permeameter.[2] From these measurements initial permeabilities were computed. For elevated temperature, measurements were made with a similar permeameter provided with a furnace compartment.[3] The bridge was also used for measuring permeabilities to small a.c. magnetizing forces when d.c. forces are superposed on the magnetic circuit. For these measurements the rings were wound with insulated copper wire after being placed in thin annular wooden boxes to protect them from strain. Hysteresis losses were computed for a few alloys from effective resistance measurements at low flux densities, made on wound rings.

Magnetization and permeability curves and hysteresis loops were plotted from ballistic galvanometer measurements. Galvanometer measurements also were made on a few alloy rods 11 in. long and 1/8 in. diameter, at a magnetizing force of 1,500 gauss. For these measurements the rods were placed in a long solenoid and the induction measured by means of an exploring coil at the center of the rod.

PROPERTIES OF THE 45 PER CENT. Ni, 25 PER CENT. Co, 30 PER CENT. Fe, COMPOSITION.

Measurements for the composition 45 per cent. nickel, 25 per cent. cobalt and 30 per cent. iron in the annealed condition are plotted in Figs. 1–7 and tabulated in Table I. The curves in Fig. 1 illustrate the permeability characteristics for this composition (No. 858–1) and for a sample of annealed Armco iron. For magnetizing forces below 1.7 gauss, the permeability is substantially constant, the variation being less than 1 per cent. This constancy is remarkable for a magnetic material having an initial permeability nearly double that of iron. Within the same range of field strengths the

[2] G. A. Kelsall, *J. O. S. A.* and *R. S. I.*, **8**, pp. 329–338, 1924.
[3] G. A. Kelsall, *J. O. S. A.* and *R. S. I.*, **8**, pp. 669–674, 1924.

permeability of the iron sample rises from an initial value of 250 through a maximum of 7,000 at a magnetizing force of 1.3 gauss and decreases to 6,300.

TABLE I.

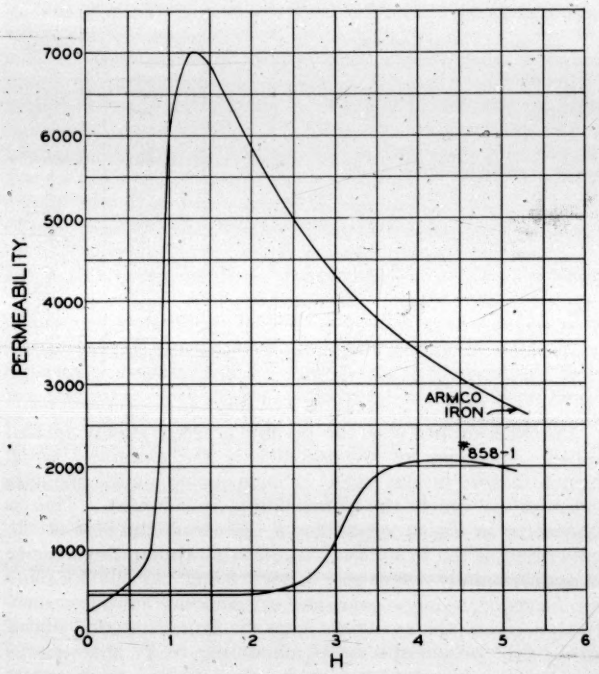
Hysteresis Loss with Different Heat Treatments for [45% Ni—25% Co—30% Fe] *Composition Perminvar.*

Heat Treatment.	*B.*	Ergs per Cm.³ per Cycle.
Air Quenched	568	18.7
	722	32
	993	57
	1,503	119
	5,010	850
	14,810	2,500
Baked at 425° C. for 24 Hours	600	0
	795	0
	1,003	15.27
	1,604	163
	4,950	1,736
	13,810	4,430
Annealed	570	0
	820	9.54
	974	15.65
	1,508	93.20
	5,050	1,185
	8,480	2,500
	14,900	3,375

Another property of the perminvar alloy closely related to the constancy of permeability is the extremely small hysteresis loss in the range of magnetizing forces and flux densities in which the permeability is constant. This is illustrated in Fig. 2 where line *a* represents the plot of the upper half of the hysteresis loop for a maximum flux density of approximately 600 gauss. Curves *b* and *c* are similar plots for Armco iron and silicon steel ($3\frac{1}{2}$ per cent. silicon) respectively. While the hysteresis loops for Armco iron and silicon steel have considerable areas amounting to 33 and 14 ergs per cubic centimeter per cycle respectively, there is no measurable area for the perminvar alloy. Although the ballistic method of measurements which was used in obtaining these curves, does not indicate very small losses readily it is evident that the losses in the perminvar alloy are of a different order of magnitude from those of the other two materials.

In order to obtain additional information in regard to the hysteresis loss of this alloy at low flux densities, the sample was measured by the inductance bridge method. It was found that the hysteresis loss at a flux density of 100 gauss was $.024 \times 10^{-3}$ ergs per cubic centimeter per cycle. The

FIG. 1.

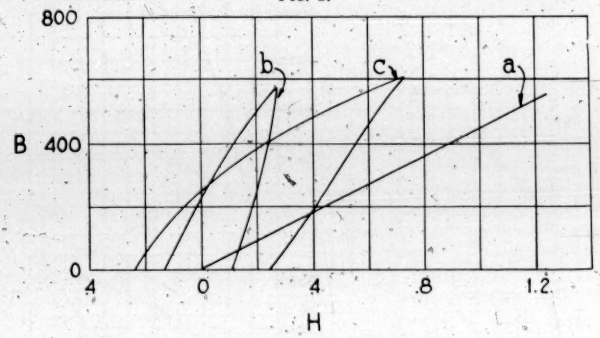


Permeability curves for Armco iron and Perminvar (45% Ni—25% Co—30% Fe).

best material in this regard previously known was permalloy, for which a sample containing approximately 78½ per cent. nickel, measured under similar conditions, had a hysteresis loss of 33×10^{-3} ergs per cubic centimeter per cycle.

The growth of the hysteresis loss and the appearance of measurable areas, and the peculiar shapes of the loops for this composition as the flux densities increase are illustrated in Fig. 3. The curve for a maximum flux density of 580

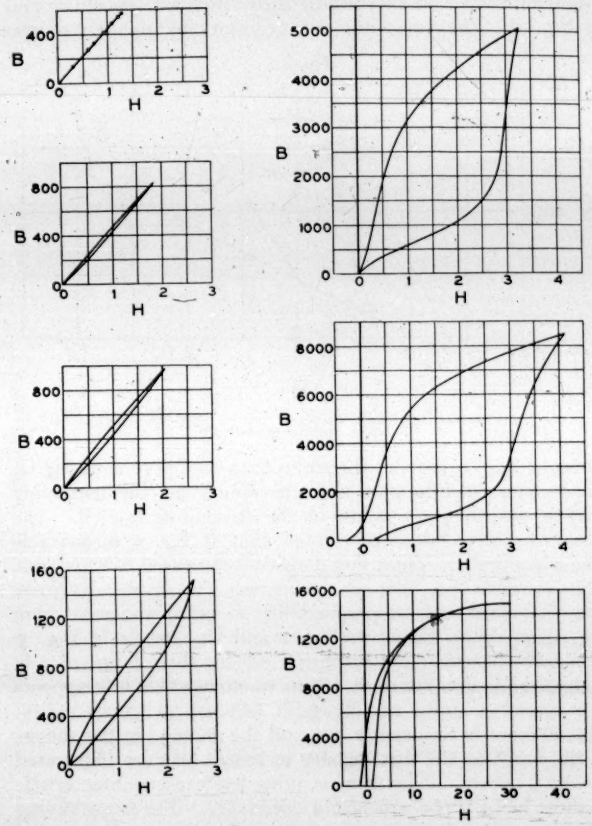
FIG. 2.



Hysteresis characteristics: *a*—Perminvar (45% Ni—25% Co—30% Fe); *b*—silicon steel; *c*—Armco iron.

gauss in Fig. 3, is from the same data as Curve *a* in Fig. 2. The circles in this plot indicate points on the ascending branch, and the dots, points on the descending branch. The hysteresis loop broadens out so that it has a measurable area when the maximum flux density is increased to 800 gauss. The existence of a close relation between the hysteresis losses and the constancy of permeability is quite apparent from the permeability curve in Fig. 1 and the curves in Fig. 3. While the permeability remains constant there is practically no hysteresis loss but as it begins to change this loss appears and increases quite rapidly with increase in permeability. The increase in the energy loss and the changes in the shapes of the loops as the flux density increases also are illustrated by these curves. The most striking hysteresis characteristic of these loops is the absence of coercivity. For loops having maximum flux densities of 5,000 or less the ascending and descending branches pass through the origin. For greater flux densities the coercivity begins to be measurable, but there is still a considerable constriction of the loop for a

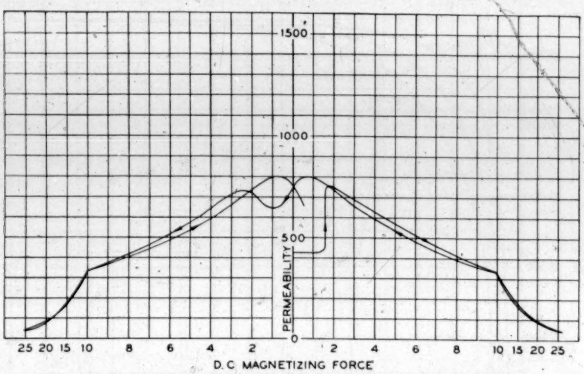
FIG. 3.



Upper halves of hysteresis loops of Perminvar (45% Ni—25% Co—30% Fe) annealed.

maximum flux density of 8,000 gauss. It is only in the loop for 15,000 gauss, that the constriction at the origin has disappeared and the loop resembles those for ordinary magnetic materials. In Table I the hysteresis losses for the complete loops are tabulated.

FIG. 4.



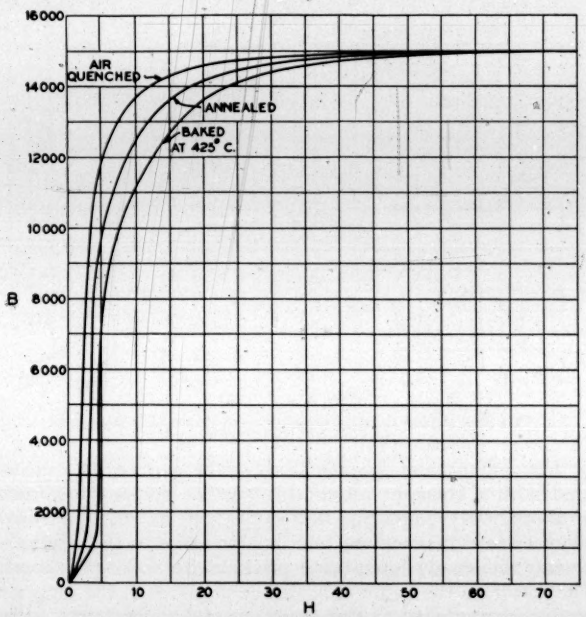
The effect of superposed d.c. fields on the a.c. permeability of Perminvars (45% Ni—25% Co—30% Fe).

Fig. 4 illustrates graphically how the permeability measured with a constant alternating current magnetizing force of about .0021 gauss and 200 cycles per second is affected when a steady magnetizing force is superposed on the magnetic circuit, the steady force being produced by a direct current. The arrows in the figure indicate the direction in the progress of the permeability as the direct current magnetizing force is varied. The permeability is substantially constant as the direct current magnetizing force increases up to approximately 1.7 gauss and it then suddenly rises as the force is increased beyond that value. This is the same field strength at which the permeability begins to increase as shown in Fig. 1.

Another characteristic of this material not found in ordinary magnetic substances also is shown in Fig. 4. After an applied d.c. magnetizing force of 25 gauss is removed,

the permeability has risen from 460 to 750. With ordinary materials, after such magnetization, the permeability is reduced, in some cases from 40 to 60 per cent. With the increase in permeability its constancy disappears both for the

FIG. 5.



Magnetisation curves for Perminvar (45% Ni—25% Co—30% Fe).

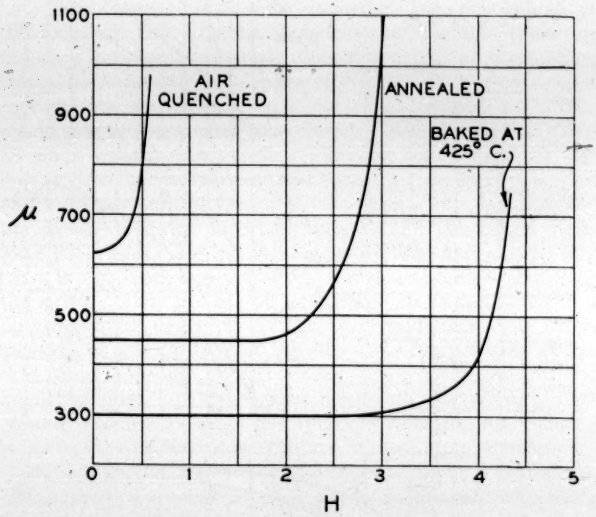
superposed condition as shown in Fig. 4, and for ordinary magnetizations at low field strengths. The hysteresis losses are also increased for corresponding flux densities. These changes in the magnetic properties are largely removed by demagnetization. The ordinary methods of demagnetization by reversals of a slowly decreasing magnetizing force has been less successful than it is with iron in returning the material to its initial state. Addition of an a.c. force

superposed on the d.c. helps materially in restoring the original magnetic properties.

EFFECTS OF HEAT TREATMENT.

The manner in which the magnetic properties of this composition are affected by the rate of cooling is illustrated in Figs. 5–7. The measurements plotted in these figures are

FIG. 6.

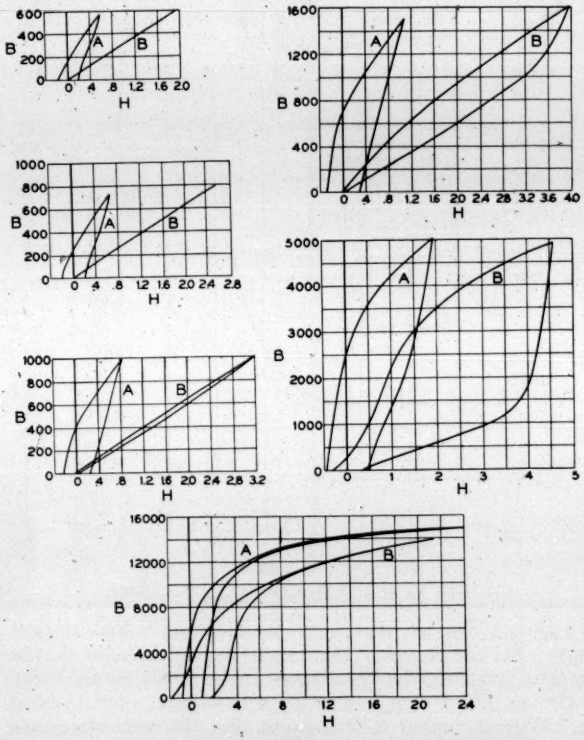


Permeability curves for Perminvar (45% Ni—25% Co—30% Fe).

from three rings, air quenched, annealed and baked, respectively. For weak fields there are large differences in the magnetic properties for these rings. The initial permeability for the quenched ring is more than twice that of the baked one. With increased field strength this difference decreases and disappears for fields over 50 gauss. The permeability variations as the strength of the field increases also show the remarkable change which heating for a long time in the critical temperature range produced in these alloys. For the

quenched ring the permeability increased from 620 to 800 for an increase of field strength from 0 to .5 gauss. For the baked ring the permeability remains constant for fields up to 2.5 gauss.

FIG. 7.



Upper halves of hysteresis loops for Perminvar (45% Ni—25% Co—30% Fe)
A—air quenched, *B*—baked at 425° C.

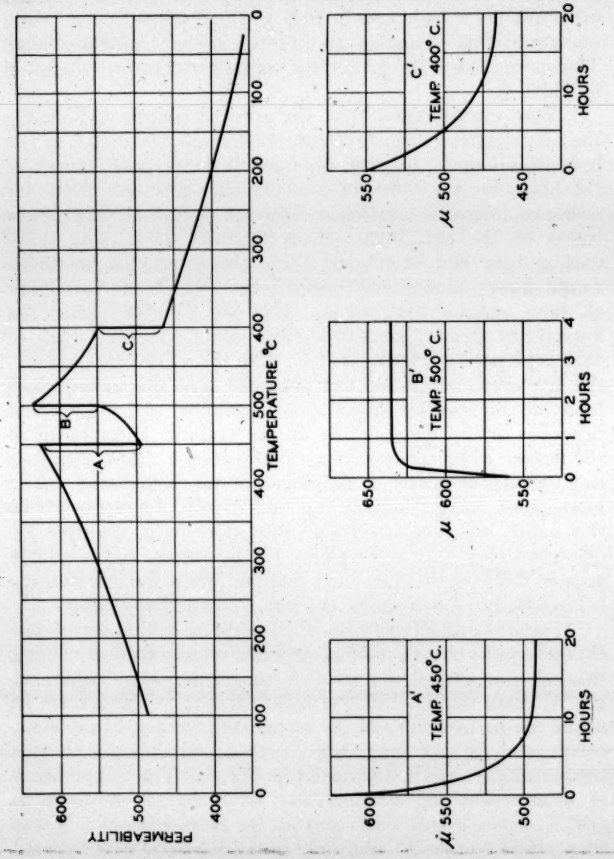
The hysteresis loss and the shapes of the loops also are affected greatly by the heat treatment. This is illustrated

in Fig. 7, where loops for a number of flux densities are plotted for two sample rings, one baked at 425° C. and the other air quenched, and in Fig. 3 where loops for the same maximum flux densities are plotted for an annealed ring. The energy losses integrated for complete loops are tabulated in Table I.

These curves show that the rate of cooling determines the magnitudes of the hysteresis losses and the shapes of the hysteresis loops. For the air quenched rings the shapes of the loops for the different flux densities resemble those for ordinary magnetic materials although a few of them show traces of the perminvar characteristics. If a more rapid cooling rate had been used these characteristics no doubt would have disappeared completely. The hysteresis loops all have considerable areas. The one for 568 gauss, the lowest flux density measured, represents an energy loss of 18.7 ergs per centimeter cube. For the same flux density, the hysteresis loops for the annealed and the baked rings have no measurable areas, the ascending and descending branches of the loops falling on the straight lines shown in the figure. This absence of measurable area extends up to a flux density of nearly 1,000 gauss for the baked ring. The increase of energy loss as the flux density increases above this value, however, is considerably more rapid than for the quenched ring. At 1,500 gauss, the hysteresis loss is a little greater than for the quenched ring and when the flux density is increased to 5,000 gauss, the loss is more than double.

It was shown above that the degree to which perminvar characteristics are developed depends on the rate of cooling through the critical temperature range, and that baking at 425° C. gave the most characteristic results. The manner in which the permeability of the 45 per cent. nickel, 25 per cent. cobalt and 30 per cent. iron composition changes in this temperature range is illustrated in Fig. 8. The temperature of an annealed ring was increased from that of the room to 450° C. where it was held constant for twenty hours. It was then raised to 500° C. and held for four hours, then lowered to 400° C. where it was held for twenty hours, and finally cooled to room temperature. Permeability measurements were made at these temperatures with an a.c. magnetizing force of .02 gauss.

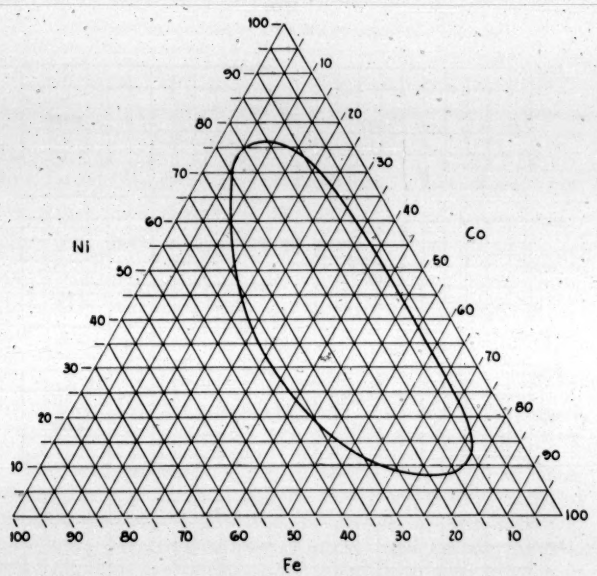
FIG. 8.



Permeability—Temperature curve for Perminvar (45% Ni—25% Co—30% Fe).

Inspection of these curves shows that in the range 400°–500° C., the permeability lags behind the temperature, and that the time required for the permeability to reach a constant value increases very rapidly below 450° C. The changes in final permeabilities with temperature decrease also rapidly

FIG. 9.



Composition diagram Ni—Fe—Co Series. Area enclosed by the curve shows compositions with marked Perminvar characteristics.

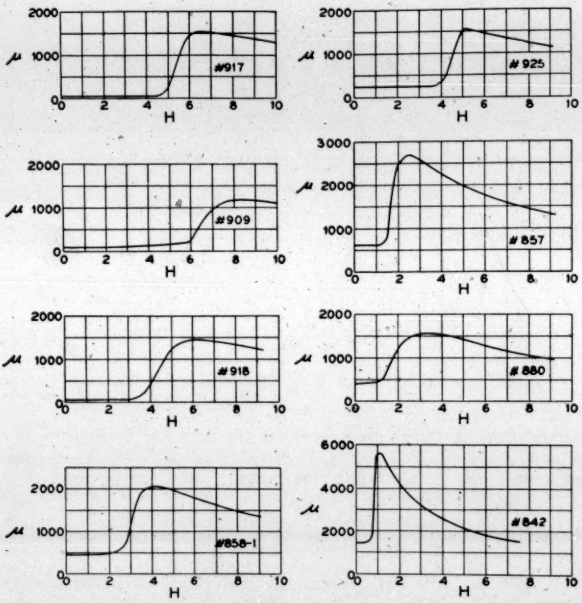
below 450° C. In fact, when the difference in permeability caused by the temperature coefficient is corrected for, the permeability of the alloy after heating at 400° C. is not very different from what it is after heating at 450° C. Other experiments show that the critical temperature range extends below 400° C., but, as would be expected, the decrease in permeability is very small. The range also extends above 500° C. for this alloy and some experiments indicate that

the upper limit is the magnetic transformation temperature which for this alloy is 725° C.

EFFECTS OF VARIATION OF COMPOSITIONS.

The composition range within which the magnetic properties characteristic of perminvar are developed pronouncedly by annealing, is represented by the area enclosed by the

FIG. 10.



Permeability curves for several compositions of Perminvar. Chemical analysis given in Table II.

curve in the triangular composition diagram Fig. 9. Magnetic properties for a few of the compositions in this area are plotted in Figs. 10 and 11. Table 2 gives their chemical analyses, initial permeability (μ_o), the maximum permeability ($\mu_{max.}$), the magnetizing forces (H) and the flux densities (B)

in gauss to which the alloys may be brought with a permeability variation not over 1 per cent., also the $(B - H)$ values for a magnetizing force of 1,500 gauss for some of the alloys, and the resistivity in microhms-cm. The hysteresis losses for a number of flux densities are given in Table 3.

TABLE II.

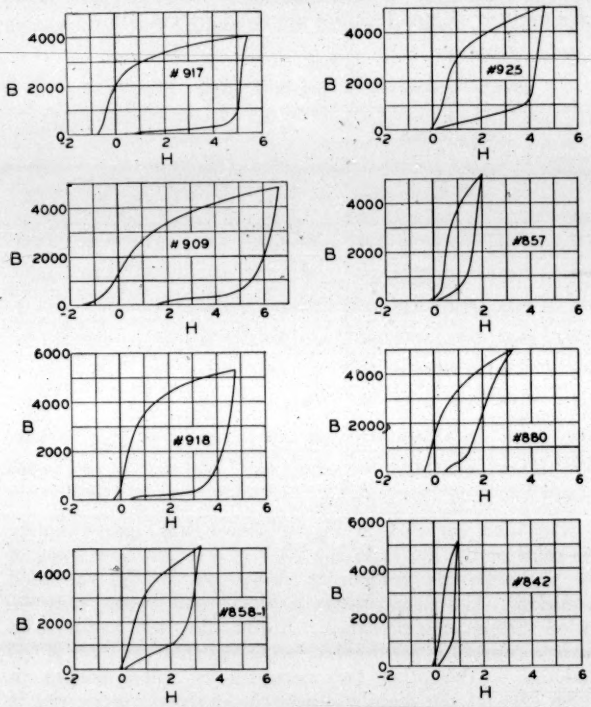
Chemical Composition and Magnetic Properties of Perminvars.

Casting Number.	Chem. Analysis.				Magnetic Properties.					Resistivity.
	Ni.	Co.	Fe.	Mn.	μ_0.	μ_m.	H for 1% Ch. in μ.	B for 1% Ch. in μ.	$B-H$ for $H=1,500$	Microhm-Cm.
917	11.35	68.10	20.36	.35	57	1,545	4.2	242	18,400	15.38
909	20.85	49.18	29.74	.31	98	1,180	4.0	396	18,200	16.59
918	20.73	68.35	10.58	.39	51	1,447	2.5	129	17,400	12.35
858–1	45.12	23.83	30.69	.46	449	2,075	1.75	793	15,600	18.63
925	50.47	29.28	20.15	.33	231	1,555	3.2	746	14,600	14.55
857	59.66	14.76	24.97	.60	631	2,680	1.15	733		17.5
880	70.29	15.23	14.57	Tr.	390	1,570	.55	216		14.13
842	73.29	5.97	20.7	.20	1,430	5,600	.55	795		15.56

The area enclosed in Fig. 9 shows that approximately one-third of the alloys in the Ni-Fe-Co series show some of the characteristic perminvar properties in the annealed condition. The proportions of nickel and cobalt may be varied through a wide range. A great deal less variation in the iron content is permissible, being less than one-half of the amounts of the other two constituents. The manner in which each of the metals affects the magnetic properties is not very clearly indicated by the numerical values in the table. Iron and cobalt appear to increase the constancy of the permeability but decrease the initial permeability values. Nickel increases the initial permeability but large percentages decrease the constancy. On the whole, in the alloys with high nickel content, the combination of high permeability and fair constancy makes for a larger range of flux densities

in which the permeability is constant and consequently also increases the range of flux densities with low hysteresis loss.

FIG. 11.



Upper halves of hysteresis loops for several Perminvar compositions. Chemical analysis is given in Table II.

Experiments on several alloys of this series indicated that by baking the alloys at 425° C. the area enclosed by the curve in Fig. 8 would be increased considerably, and possibly would include some of the binaries of these metals.

TABLE III.

Hysteresis Loss.

Casting Number.	*B.*	Ergs per Cm.³ per Cycle.	*B.*	Ergs per Cm.³ per Cycle.	*B.*	Ergs per Cm.³ per Cycle.	*B.*	Ergs per Cm.³ per Cycle.	*B.*	Ergs per Cm.³ per Cycle.
917	280	8	625	150	1,700	1,040	3,950	2,740	15,500	14,160
909	—	—	620	36	1,030	299	4,800	3,330	15,200	12,460
918	—	—	750	247	—	—	5,270	2,605	—	—
858–1	566	0	827	9.5	1,508	93	5,050 8,480	1,185 2,500	14,900	3,375
925	560	0	—	—	2,000	468	5,000	2,020	13,200	4,965
857	145	0	840	8.4	1,520	88	5,200 8,250	632 1,240	13,250	1,508
880	320	0	—	—	1,470	116	5,000	1,012	10,300	2,435
842	500	0	—	—	1,530	23	5,100	348	11,500	783

DISCUSSION.

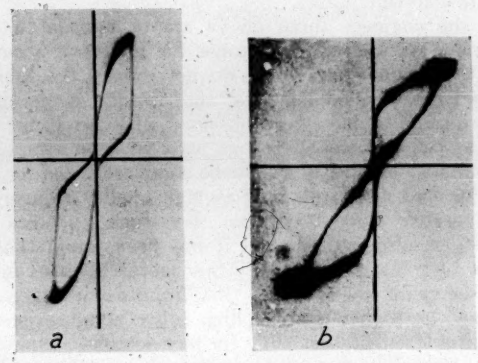
While this paper is concerned primarily with the study of the magnetic properties of these alloys and the dependence of these properties on composition and on heat treatment, some of the results are of considerable theoretical interest, as they suggest the manner in which the unusual magnetic properties are acquired by the alloys. It was shown in the heat treating experiments that the unusual magnetic properties resulted from suitable heat treatment of certain compositions. Slow cooling through a rather narrow temperature range, or continuous heating for a long time at the lower end of this range resulted in alloys which had marked perminvar characteristics. Rapid cooling through this temperature range usually did not develop these characteristics. From the measurements at elevated temperatures, Fig. 8, it was shown that in the temperature range from 400° C. to 500° C., the change in the alloys is quite rapid at the higher temperature, but that the rate of stabilization slows up as the temperature decreases. When the alloy is heated and cooled through a temperature cycle in this manner, the permeability changes progressively and at each temperature in the cycle the alloy reaches a stable condition if the rate of cooling or heating is slow enough. There is a striking similarity in the manner in which these changes in permeability are developed, and in the progress of the constitutional changes in an alloy which at high temperatures is a homogeneous solid solution, but as the temperature falls becomes saturated and segregates into a mixture of two solid solutions of different concentration.

That such a segregation takes place in the slowly cooled alloys is also supported by a study of the differences in the shapes of the hysteresis loops of the quenched and the slowly cooled alloys. Ordinarily, the widest part of a hysteresis loop of a homogeneous material is the intercept on the H axis. All the loops of the air-quenched alloys have these characteristics. Gumlich [4] has shown that if a magnetic circuit is made up two materials of different magnetic properties, the loops may assume a variety of shapes, ranging from that

[4] E. Gumlich, Arch. f. Elektretechnik, Vol. 9, p. 153, 1920.

of the homogeneous material to one in which two branches converge at the origin into a single line. This constriction of the hysteresis loop is also illustrated for a parallel bi-metallic magnetic circuit in Fig. 12 where loops *a* and *b* are

FIG. 12.



Hysteresis loops: *a*, Perminvar; *b*, Bi-metallic rod. Loops traced with a cathode ray oscillograph.

traced for a perminvar core and a bi-metallic rod, respectively. The rod was 15 in. long and consisted of a core of .04 in. diameter unannealed piano wire and a .006 in. wall permalloy tube, heat treated to give high permeability, and fitting closely to the wire. Though the magnetic circuit condition for the perminvar core is not the same as for the bi-metallic rod, the similarity of the two loops is marked and supports the theory that the constricted loop of the perminvar core is caused by segregation in the alloy.

The electrical resistance also is affected by the slow cooling. An air-quenched alloy of the 45 per cent. nickel, 25 per cent. cobalt and 30 per cent. iron composition was 10 per cent. lower in resistivity after it had been baked at 425° C. This change is also in line with the idea that segregation takes place when the perminvar alloys are cooled slowly.

While these considerations point to a satisfactory explanation for the constriction of the hysteresis loops they do not

explain the extremely low hysteresis losses of the alloys at low flux densities. This characteristic of perminvar suggests that one of the constituents which is segregated by the heat treatment is itself a material of much lower hysteresis loss than any previously known material and that the other constituent suffers relatively little change of magnetization at low magnetizing forces.

To the engineer these alloys are of unusual interest. They may be used to advantage for magnetic structures where the magnetizing forces do not exceed the limits of constancy of permeability for the various compositions. Interesting results have been obtained with the 45 per cent. nickel, 25 per cent. cobalt and 30 per cent. iron composition for continuous loading of telephone conductors and for cores of loading and filter coils used in high quality transmission and in carrier current circuits. For such purposes high resistivity is also desired, and it has been found that the addition of a few per cent. of other metals such as molybdenum serves for this purpose. For circuits requiring greater constancy or higher permeability other compositions are more suitable. The best alloy for any specific circumstance may be selected from a study of the magnetic properties of the various compositions.

BELL TELEPHONE LABORATORIES,
NEW YORK, N. Y.,
July 9, 1928.

THE MAGNETIC FIELD INTENSITY AT ANY POINT IN THE PLANE OF A CIRCULAR LOOP.

BY

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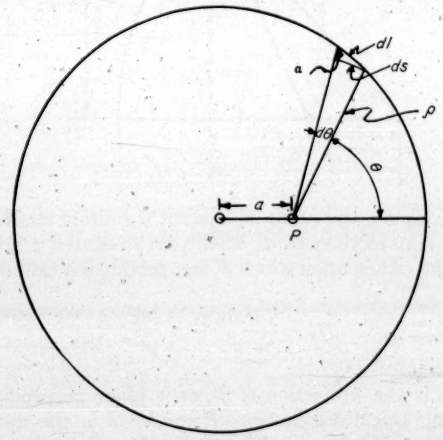
Instructor, School of Electrical Engineering, Purdue University.

In this paper a method is developed for calculating the magnetic field intensity at any point in a circular loop in which an electric current flows. This method is based upon the familiar relation given in Ampere's law,

$$H = \frac{I \cdot dl \cdot \sin \alpha}{\rho^2}.$$

Fig. 1.



The problem of calculating the field intensity at the center of such a loop is used in most treatises on magnetism, and has become one of the classical examples of the application

of Ampere's Law. For this special case the problem is much simplified, since I, ρ, and sin α are all constants (ρ = radius; sin α = 1), whence,

$$H = \frac{I}{r^2}\Sigma dl = \frac{2\pi r I}{r^2} = \frac{2\pi I}{r}.$$

When, however, the point at which the field intensity is desired is not at the center, neither ρ nor sin α remain constant, and the problem becomes much more involved. A solution for this general case is given below. Referring to

FIG. 2.

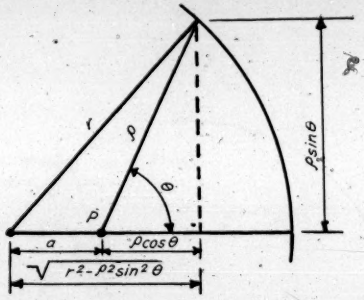


Fig. 1, consider the point P, distant a centimeters from the center. Any increment, dl, of the circle located at an angle, θ, from the radius upon which P lies, produces a field intensity at P, of

$$dH = \frac{Idl \sin \alpha}{\rho^2} = \frac{Ids}{\rho^2},$$

where ds is the projection of dl, on a plane perpendicular to ρ, ρ being the distance from P to dl. I is the current in the wire in abamperes. But, $ds = \rho d\theta$, whence,

$$dH = \frac{I\rho d\theta}{\rho^2} = \frac{Id\theta}{\rho}. \qquad (1)$$

The field intensity at any point P, distant a centimeters from the center is then

$$H_a = \int_0^{2\pi} \frac{Id\theta}{\rho}. \tag{2}$$

In the above integral, ρ as well as θ, is variable, and hence must be expressed in terms of θ before integration is possible. To evaluate ρ in terms of θ, consider the diagram in Fig. 2.

Referring to this figure it is seen that

$$\sqrt{r^2 - (\rho \sin\theta)^2} - a = \rho\cos\theta;$$
$$\sqrt{r^2 - \rho^2\sin^2\theta} = a + \rho\cos\theta.$$

Squaring both sides gives

$$r^2 - \rho^2\sin^2\theta = a^2 + 2a\rho\cos\theta + \rho^2\cos^2\theta,$$
$$r^2 - a^2 - \rho^2(\sin^2\theta + \cos^2\theta) - 2a\rho\cos\theta = 0.$$

But since $(\sin^2\theta + \cos^2\theta) = 1$,

$$\rho^2 + (2a\cos\theta)\rho + (a^2 - r^2) = 0.$$

Solving for ρ,

$$\rho = -a\cos\theta \pm \sqrt{a^2\cos^2\theta + (r^2 - a^2)}. \tag{3}$$

Since ρ is always positive and real, the quantity under the radical must be positive, and the sign before the radical must also be positive.

Substituting the value for ρ as found in equation (3), into equation (2), gives

$$H_a = I\int_0^{2\pi} \frac{d\theta}{-a\cos\theta + \sqrt{a^2\cos^2\theta + (r^2 - a^2)}}. \tag{4}$$

Multiplying numerator and denominator in (4), by the conjugate of the denominator, gives

$$H_a = I\int_0^{2\pi} \frac{-a\cos\theta - \sqrt{a^2\cos^2\theta + r^2 - a^2}}{a^2\cos^2\theta - a^2\cos^2\theta - r^2 + a^2} d\theta,$$

whence

$$H_a = \frac{I}{r^2 - a^2}\int_0^{2\pi} a\cos\theta d\theta + \frac{I}{r^2 - a^2}\int_0^{2\pi}\sqrt{a^2\cos^2\theta + (r^2 - a^2)}\cdot d\theta. \quad (5)$$

Upon integration the first part of equation (5),

$$\frac{I}{r^2 - a^2}\int_0^{2\pi} a\cos\theta d\theta, \text{ vanishes leaving}$$

$$H_a = \frac{I}{r^2 - a^2}\int_0^{2\pi}\sqrt{a^2\cos^2\theta + (r^2 - a^2)}\cdot d\theta. \quad (6)$$

Equation (6) may be transformed by letting

$$a^2\cos^2\theta - a^2 = -a^2\sin^2\theta,$$

whence

$$H_a = \frac{I}{r^2 - a^2}\int_0^{2\pi}\sqrt{r^2 - a^2\sin^2\theta}\, d\theta,$$

$$= \frac{Ir}{r^2 - a^2}\int_0^{2\pi}\sqrt{1 - \frac{a^2}{r^2}\sin^2\theta}\, d\theta. \quad (7)$$

Equation (7) is a common type of elliptic integral (for its evaluation see Pierce's Table of Integrals, form 527), and has the following value:

$$\int_0\sqrt{1 - k^2\sin^2\theta}\, d\theta = \frac{2}{\pi}\phi E + \sin\phi\cdot\cos\phi,$$

where E is an elliptic integral, the value of which for any particular value of k, may be found in a table of elliptic integrals. K, in equation (7) is a/r; ϕ, the upper limit, in equation (7), is 2π. Substituting these values gives for the integral,

$$\int_0^{2\pi}\sqrt{1 - \frac{a^2}{r^2}\sin^2\theta}\, d\theta = \left[\frac{2}{\pi}\cdot 2\pi E + \sin 2\pi\cdot\cos 2\pi\right] = 4E.$$

Hence the value of equation (7) is

$$H_a = \frac{Ir}{r^2 - a^2}\cdot 4E. \quad (8)$$

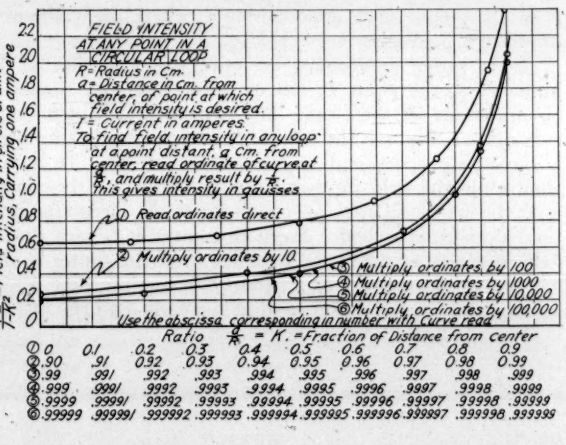
Equation (8) gives the field intensity at any radius a centimeters from the center of a circular loop of wire carrying a current, I abamperes. For any particular value of $k = a/r$, the value of E may be found directly from a table of elliptic integrals.

As a check, let us consider the field intensity at the center of the loop. Here, $k = 0$; $E = \pi/2$; whence

$$H = \frac{Ir2\pi}{r} = \frac{2\pi I}{r}.$$

This agrees with the result obtained by applying Ampere's Law directly as illustrated at the beginning of this paper.

FIG. 1A.


FIELD INTENSITY AT ANY POINT IN A CIRCULAR LOOP
R = Radius in Cm.
a = Distance in cm. from center, of point at which field intensity is desired.
I = Current in amperes.
To find field intensity in any loop: at a point distant, a Cm. from center, read ordinate of curve at a/R, and multiply result by I/R. This gives intensity in gausses.
4E = Field Intensity in circle of unit radius, carrying one ampere
I/R
1) Read ordinates direct
2) Multiply ordinates by 10
3) Multiply ordinates by 100
4) Multiply ordinates by 1000
5) Multiply ordinates by 10,000
6) Multiply ordinates by 100,000
Use the abscissa corresponding in number with Curve read
Ratio a/R = K. = Fraction of Distance from center
1) 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
2) .90 .91 .92 .93 0.94 0.95 0.96 0.97 0.98 0.99
3) .99 .991 .992 .993 .994 .995 .996 .997 .998 .999
4) .999 .9991 .9992 .9993 .9994 .9995 .9996 .9997 .9998 .9999
5) .9999 .99991 .99992 .99993 .99994 .99995 .99996 .99997 .99998 .99999
6) .99999 .999991 .999992 .999993 .999994 .999995 .999996 .999997 .999998 .999999

It will be noted that the field intensity, H, as determined in equation (8), becomes infinite when $a = r$. This results because the preliminary assumption, $dH = Ids/\rho^2$, holds only for points outside the conductor itself. Hence equation (8) is valid for all values of a less than $(r - s)$, where s is the radius of the conductor, but does not hold for greater values of a.

Equation (8) may be expressed in terms of k, by dividing numerator and denominator by r^2, whence

$$H_a = \frac{I}{r}\left[\frac{4E}{1 - k^2}\right]. \tag{9}$$

If in equation (9), the term, $4E/(1 - k^2)$, is plotted against values of k, then the resulting curve ordinates, read at the abscissa a/r, when multiplied by I/r, will give the field intensity at any radius a, centimeters from the center of any loop the radius of which equals r centimeters. Such a curve has been drawn in Fig. 1*A*. This curve has been divided into a number of sections as may be seen in the figure. By this scheme it was possible to use a combination of scales that permit fairly accurate reading of the curve, even for values of k approaching 1, where the value of the ordinate is increasing very rapidly.

It is rather interesting to note the variation of field intensity as the point P, moves from the center toward the circumference of the loop. This variation is shown best on curve No. 1, Fig. 1*A*, since in this curve the height of ordinate is directly proportional to the field intensity. It is noted that while the field intensity remains quite nearly constant near the center, it rises very rapidly as the circumference of the loop is approached. From this curve it is seen that the field intensity at 0.8 of the distance from the center is about 2.3 that at the center; at k equals 0.9, the intensity is about 4 times that at the center, and at k equals 0.99 the intensity is about 33 times that at the center.

THE USE OF A BROAD FOCUS COOLIDGE TUBE IN ACCURATE RADIOGRAPHIC LOCALIZATION.

BY

OTTO STUHLMAN, Jr., Ph.D.,

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IN the localization of foreign bodies in the human anatomy or in parallel cases, in the localization of imperfections in technical structures, there are, generally speaking, three principal methods by which information of a quantitative nature is obtained concerning the position of an imbedded invisible body.

(1) By viewing with a screen or making radiographs of the suspected region in two directions taken at right angles to each other.
(2) By stereoscopic methods.
(3) By triangulation.

Where speed is not the governing factor but where a permanent, accurate record is of paramount importance, or where the structure other than the human anatomy is too thick for fluoroscopic examination, then the triangulation method supplemented by a radiographic plate record must be resorted to.

The scientific requirements of a good triangulation method are that it should possess simplicity, reproducibility and accuracy. In its simplest form, the target of the Coolidge tube is set at a predetermined distance H above the film. Two exposures are made of the body on the same film, the first with the target vertically above the body and the second, after the target has been shifted a known distance, "X," in a horizontal direction. The film now shows two shadows, the second displaced a small distance, "d," parallel to the first. In Fig. 1 is shown the geometry of these positions drawn to scale. Here h is the height of the body above the plane of the film PP', H the predetermined height of the center of the target above the same plane. $(H - h)$ is the

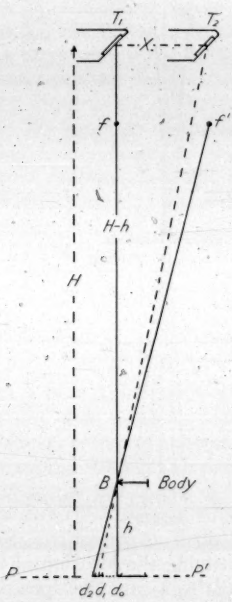
height of the center of the target above the body, X the predetermined displacement of the target resulting in the displacement of the second shadow from d_0 to d_2. Geometrically speaking, if the source of the energy is a point lying in the face of the target at T_1 displaced to T_2, then the shadow cast by the arrow-head of the body will be displaced from d_0 to d_1. The height of the body above the plane is then $h = Hd/(X + d)$.

This is the relation used in all literature describing localization methods and does not take into consideration a variable of prime importance, namely, that the point T_2 is not the origin of the rays casting the shadow of the body in the plane PP'. The measured shadow extends from d_0 to d_2 while the predicted geometrical shadow only extends from d_0 to d_1. The origin of the point d_2 does not lie at T_2 but at f' below the target. Previous methods tacitly assume that the X-ray beam is a geometrical cone of energy of small numerical aperture with its apex lying in the center of the face of the target T. As a matter of fact this is only a very close approximation in a very fine focus tube, a tube with a small focal spot and with very uniform energy distribution over its surface.

The design of the Coolidge tube is such as to make the filament emit a tubular beam of electrons with minimum intensity at the outer and inner periphery of the tube. A pinhole camera image of the X-ray beam will show what is the distribution of energy over its surface. Except in case of a very sharp focus tube this energy distribution will give focal spot images of shapes comparable to balloon tires which are slightly elongated along a line lying parallel to the axis of the tube. To visualize the conditions let us refer to Fig. 2. The electron stream as here shown is concentrated near the outer boundary with relatively few at the center of the stream. This is due to the higher temperature on the periphery of the spiral heater element. The generated X-ray energy is hence principally confined to the area roughly indicated by the arrows at "a" and "b." If these areas are now reproduced through the pinhole in the form of a point for point image in the plane PP', we see how the balloon tire shape photographic image is generated by the overlapping of the

various beams originating at the areas "a" and "b." The broader the focus of the tube the more pronounced the distortion of this area in the plane PP'. It will be noticed however that geometrically a virtual focus exists at f_a due to the crossing of the beams generated by the area "a" and a corresponding virtual focus at f_b due to the area "b." So that on the average a virtual focus $(f_a + f_b)/2 = f$ lies

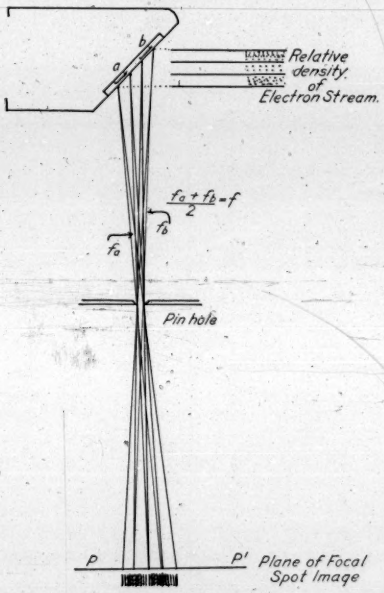
FIG. 1.



below the center of the target. This virtual focus may be considered as acting like a point source, sending out a conical pencil of X-ray energy effecting the plate PP' in the usual way. Interposing an opaque body B (Fig. 1) into such a beam of energy allows us to arrive at the geometrical size of the shadow in the plane PP' as d_0d_2 and not as d_0d_1 as the

simple geometrical analysis would predict, since the horizontal displacement of the target from T_1 to T_2 really displaces the virtual focus from f to f', where f', and not T_2, acts as the source to cast the shadow d_0d_2.

FIG. 2.



In order to determine the location of the virtual focus f, all one needs to do is to locate the apex of the cone forming the image PP' as in Fig. 2. These data are furnished by the diameter of the focal spot image PP', position and size of pinhole and position of target with respect to the plane PP'.

With a very sharp focus tube no appreciable error is introduced in the value of h, the height of the foreign body above the plane, by assuming that f merges into the face of the target.

In other words, the shifting of the target through a horizontal distance X will lead to a shadow shift d_0d_1 but not to the observed shift d_0d_2. This shift of the target is, however, equal to the horizontal shift X of the virtual focus f to f' leading to a geometrical ray connecting f' to B and intersecting the shadow at the expected point d_2. (Fig. 1.)

Allowing for this correction we find that the height of the body above the plane PP' is now given by $h = d(H - f)/(X + d)$, where all the letters have the same significance as in Fig. 1 and f is the distance of the virtual focus below the center of the target and d the measured shadow displacement d_0d_2 as taken from the plate.

One naturally inquires as to the practical value of such discriminations. An example of the results obtainable with and without this focal correction using a medium broad focus Coolidge tube is shown in Table I.

TABLE I.

d	h	h_2	h_1
.39	4.1	4.24	4.67
.66	7.1	6.92	7.59
1.00	10.3	10.0	11.0
1.76	16.2	16.0	17.6

A lead plate 3 mm. thick with a sharp edged slot cut into it 6 × 0.3 cm. was used as a foreign body. It was placed in a horizontal plane at a distance "d" cm. above the plane of a photographic film which was inclosed in a cardboard cassette. The center of the target of the Coolidge tube was set at 82.5 cm. above the film and displaced in each observation 6.5 cm. The displacement of the shadow was measured by means of a pair of drawing instrument dividers to the nearest tenth of a millimeter. The height "h" of the foreign body (the slot) above the plane of the film was then computed, first uncorrected for virtual focus as $h_1 = dH/(X + d)$ and, second, corrected for virtual focus as $h_2 = d(H - f)/(X + d)$. It is obvious that the corrected values in Table I represented by the column h_2 are 10 per cent. nearer the true values of "h" than those computed from the uncorrected formula. The values of h_2 show on an average only a 2 mm. departure

from their true predetermined values. Accurate results are thus obtained comparable to very elaborate technique aided by a very fine focus tube.

In general the broader the focal spot of the tube the greater the error of localization if the target is taken as the source of the X-radiation. The error may, however, be reduced to a minimum if the position of the virtual geometrical focus existing below the target is used instead of the center of the target as the height of the source producing the displaced shadows. Thus a medium or broad focus tube can be used in general practice where the frequency of the demand for this particular type of technique does not warrant the purchase of an additional fine focus tube.

In view of the fact that probably no two Coolidge tubes have the same type of focal spot with identical energy distribution over its area it follows that the position of the virtual focus for every tube must be experimentally determined.

The procedure for determining the geometrical position of the virtual focus is as follows:

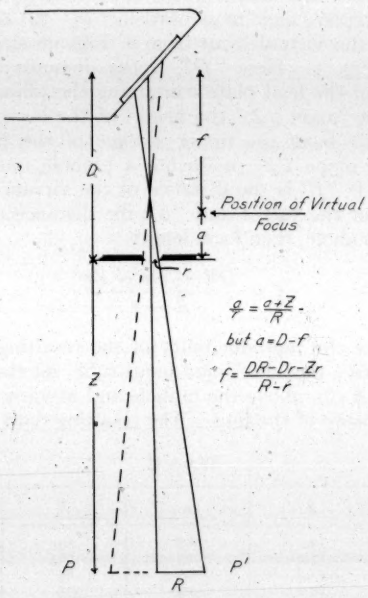
Make four or more focal spot pictures on a single film as outlined in the "Instruction Book for Coolidge X-Ray Tubes" as issued by the General Electric Co., of Schenectady, N. Y. If this is not available the following summary will suffice.

"Take a small sheet of lead, say 3 mm. (1/8 inch) thick and of the right size to take the place usually occupied by the diaphragm in the cone of the tube holder. Make a conical depression in the center with a machinist's prick punch or other blunt nosed tool and then with a small drill, open the hole at the bottom of the depression to a diameter of about 1 mm. With the lead plate in place, measure the distance from the center of the target to the pinhole directly below it. This measurement must be made to 2 mm. (1/16 inch). Place a film at some known distances below the pinhole, say 15, 20, 25 and 30 cm. Since the size of the focal spot image at any given distance is always the same regardless of the current and voltage employed, a long time exposure will show the full extent of the focal spot and a short exposure the distribution of the energy over it." The

developed image on the film will resemble a slightly distorted perspective of an automobile balloon tire.

For each of the above images measure the mean outer diameters. Lay off to scale these dimensions as shown in Fig. 2. First lay off the inner and outer diameters of the image in the plane PP' formed by placing the pinhole 15 cm.

FIG. 3.



above the plate. Erect a perpendicular 15 cm. to the position of the 2 mm. pinhole. Then place above the pinhole the 45° tungsten target at the predetermined distance from the pinhole to center of target.

Reproduce the focal spot image point for point as originating first from the lower third of the target and then from the upper third of the target as at "*a*" and "*b*." The

intersection of the lines show graphically the location of the virtual foci marked f_a and f_b. The mean distance $(f_a + f_b)/2 = f$ of these two foci is here considered as the location of the virtual focus associated with the tube. It will be noticed that the distortion of the focal spot in a direction along the axis of the tube is produced by the 45° slope of the target.

By using the predetermined positions and the data obtained from the above focal spot determinations it is perhaps simpler and more satisfactory to compute the position of the virtual focus from a diagram similar to that shown in Fig. 3. Here "D" is the distance between the lower face of the lead plate containing the pinhole of radius "r" and the target "Z" the height of the lower face of the pinhole plate from the upper surface of the photographic film in the plane PP' producing a pinhole image of outer radius R. If "f" is the distance of the virtual focus below the center of the target and "a" the distance of this focus above the pinhole, then focal length

$$f = \frac{DR - Dr - Zr}{R - r}.$$

To illustrate the reproducibility of the resulting values of f as applied to a medium broad focus tube, set the latter with its target 8.8 cm. above the pinhole and at various heights Z above the plane of the film. The resulting data are given in Table II.

TABLE II.

D	Z	r	R	f
8.8	14.2	.05	.59	7.49
8.8	17.2	.05	.685	7.46
8.8	21.2	.05	.85	7.47
8.8	24.2	.05	.95	7.46
				mean $f = 7.5$

The diameter of the pinhole was 1 mm. The images of the focal spots obtained at various distances Z had external radii whose values are indicated by the column marked R. The focal distances as computed from the above data are given in the column marked f. The mean value thus obtained

is a fair representation of the accuracy of the method employed.

In the case of a small focal spot the central circular area of the focal spot image shrinks to a negligible diameter. If, in addition, the electron stream is of uniform density then the distance from the target to the virtual focus becomes negligibly small and the focus may for all practical purposes be considered as located at the surface of the target.

The data for this discussion were obtained by G. W. Heinitsh and J. E. Morris.

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Electrical Methods of Hygrometry. P. W. BURBIDGE AND N. S. ALEXANDER. (*Proc. Phys. Soc.*, London, vol. 40, Pt. 3, 1928.) It is surprising that the extension of scientific research and the development of methods of measurement have done so little for hygrometry. There remain the three standard ways of determining the humidity of the air, by the wet and dry bulb thermometers, by the dew point and by the change of length of a hair. Not one of them can rival in accuracy and convenience the methods used to measure other far less obvious and less practically important quantities. This paper gives an account of an effort to devise better means of measurement. Pure cotton wool was placed between two electrodes placed in a box containing the air of which the humidity was to be determined. No polarization showed itself and Ohm's Law was followed. The electrical resistance for different relative humidities was measured, the temperature being constant. On plotting the logarithm of the resistance against the relative humidity a straight line was obtained. "At high humidities the resistance decreased enormously, and trustworthy readings could not be obtained above 95 per cent. humidity." Besides this the time lag was excessive. By an improved arrangement the lag was reduced to 5 or 6 minutes. The resistance of human hair freed from grease also was measured. When the relative humidity varied from 0 to 50 per cent. the change in resistance was rather small. It was greater for higher humidities.

A further endeavor was made to correlate humidity with the mobility of ions in air. Tyndall and Grindley had shown that the mobility of negative ions sinks from 2.15 in dry air to 1.6 in air saturated with water vapor. Here again failure was encountered. It is a promising sign that physicists are working upon the problem of measuring humidity. Recognized problems have a way of becoming solved. G. F. S.

AN EXPERIMENTAL INVESTIGATION OF FORCED VIBRATIONS.

BY

L. W. BLAU, M.A.

Abstract.

The solution of the differential equation $y'' + 2Ry' + n^2y = E \cos pt$ is written in a new form which clearly exhibits many important facts thus far overlooked by theoretical and experimental investigators. Writing $s = n - p$, and $\Delta n = n - \sqrt{n^2 - R^2}$, it is found: (*a*) When $s \neq \Delta n$, there are "beats," and the first "beat" maximum is greater than any later maximum while the first "beat" minimum is less than any later "beat" minimum. The "beat" frequency is $(s - \Delta n)/2\pi$. (*b*) When $n^2 - p^2 = R^2$, there are no "beats," and the resultant amplitude grows monotonically from zero to the amplitude of the forced vibration, (*c*) At resonance, when $n = p$, we still have maxima which occur with a frequency $\Delta n/2\pi$ in a damped system. (*d*) The absence of "beats" is neither a sufficient nor a necessary condition for resonance in a damped system.

In the experimental investigation the upper extremity of a simple pendulum was moved in simple harmonic motion and photographic records obtained of the motion of the pendulum bob. Different degrees of damping were used, ranging from very small to critical.

The experimental results are in excellent agreement with theory.

1. INTRODUCTION.

THE subject of forced vibrations has been investigated rather fully, both mathematically [1] and experimentally,[2] but neither the relations derived mathematically nor the experimental results exhibit clearly the principal facts of this type of motion. In the following pages an equation derived and published elsewhere [3] is employed, and an experimental arrangement is described which permits of the investigation of forced vibrations. Photographic records are shown which verify the theoretical results.

[1] Rayleigh, "Theory of Sound," 2d Ed., Macmillan, 1894. Duffing, "Erzwungene Schwingungen bei veraenderlicher Eigenfrequenz und ihre technische Bedeutung," F. Vieweg u. Sohn, Braunschweig, 1918. Riemann-Weber, "Die Differential- und Integralgleichungen der Mechanik und Physik, zweiter, physikalischer Teil, F. Vieweg u. Sohn, Braunschweig, 1927, pp. 86 ff.

[2] Barton and Browning, *Phil. Mag.*, 36, pp. 169–178, 1918.

[3] *The American Mathematical Monthly*, 35, June–July, 1928.

2. THEORY.

In the paper referred to above [3] the differential equation of forced vibrations was written

$$\ddot{y} + 2R\dot{y} + n^2 y = E \cos pt, \tag{1}$$

where y = displacement from the position of rest,

R = damping factor,

$\frac{n}{2\pi}$ = natural frequency of the vibrating system

and $\frac{p}{2\pi}$ = frequency of the impressed force.

The general solution of (1), for the case when R^2 is less than n^2, is

$$y(t) = A \cos pt + B \sin pt + Ce^{-Rt} \cos \sqrt{n^2 - R^2}t + De^{-Rt} \sin \sqrt{n^2 - R^2}t,$$

where

$$A = \frac{(n^2 - p^2)E}{(n^2 - p^2)^2 + 4R^2p^2} \tag{2}$$

and

$$B = \frac{2RpE}{(n^2 - p^2)^2 + 4R^2p^2}.$$

If we now impose the initial conditions

$$y(0) = 0; \qquad \dot{y}(0) = 0,$$

that is, that the initial displacement and the initial velocity are each equal to zero, then the constants C and D in (2) must have the following values:

$$C = \frac{(p^2 - n^2)E}{(n^2 - p^2)^2 + 4R^2p^2},$$
$$D = \frac{-RE(n^2 + p^2)}{\sqrt{n^2 - R^2}\,[(n^2 - p^2)^2 + 4R^2p^2]}. \tag{4}$$

I have shown recently [3] that equation (2) may be written

$$y(t) = \Big\{ A^2+B^2+(C^2+D^2)e^{-Rt} - 2e^{-Rt}\sqrt{(A^2+B^2)(C^2+D^2)}\,\sin\Big[(s-\Delta n)t + \tan^{-1}\frac{C}{D}+\tan^{-1}\frac{B}{A}\Big]\Big\}^{\frac{1}{2}} \times\left(\sin pt+\tan^{-1}\frac{A+e^{-Rt}\sqrt{C^2+D^2}\,\sin\left[\Delta nt+\tan^{-1}\frac{D}{C}\right]}{B+e^{-Rt}\sqrt{C^2+D^2}\,\cos\left[\Delta nt+\tan^{-1}\frac{C}{D}\right]}\right), \tag{5}$$

where $s = n - p$, and

$$\Delta n = n - \sqrt{n^2 - R^2}.$$

If we take the differential equation

$$\ddot{y} + 2R\dot{y} + n^2y = E \sin pt, \tag{6}$$

which applies to the case of forced vibrations investigated experimentally by the writer, subject to the conditions (3), the solution may be written in the form (5), but the constants will then have the following values:

$$A = \frac{-2RpE}{(n^2-p^2)^2+4R^2p^2},$$
$$B = \frac{(n^2-p^2)E}{(n^2-p^2)^2+4R^2p^2},$$
$$C = \frac{2RpE}{(n^2-p^2)^2+4R^2p^2} \quad \text{and} \tag{7}$$
$$D = \frac{E(2R^2p-n^2+p^2)}{\sqrt{n^2-R^2}[(n^2-p^2)^2+4R^2p^2]}.$$

Equation (5) is better adapted to the investigation of the resultant displacement than equation (2). We make note of the following facts from the expression for the amplitude of the resultant displacement and from the phase angle as given by (5):

1. When s is different from Δn, there are "beats," forming a regularly spaced array of maxima and minima, and the first

"beat" maximum is greater than any later maximum, while the first minimum occurring after $t = 0$ is smaller than any later minimum. It is to be noted that the frequency of these "beats" is $\frac{s - \Delta n}{2\pi}$. Hence, in a damped system under forcing, the "beat" frequency is not equal to the difference between the frequencies. True beats are given by damped systems only when the vibrations of the systems are separately maintained.

2. When $n^2 - p^2 = R^2$, there are no "beats," and the resultant amplitude grows monotonically from zero to the amplitude of the forced vibration in the steady state. The difference between the squares of the frequencies in this special case has been called the critical frequency-difference. Only when this condition is satisfied is it true that "While the free vibration is dying away, the resultant motion which is under observation grows from nothing to the fixed amplitude and phase of the forced vibration." [4]

3. When $n = p$, we still have maxima which occur with a frequency $\frac{\Delta n}{2\pi}$ in a damped system. The solution (5) of equation (6) satisfying (3) then reduces to

$$y(t) = \frac{E}{2Rn}\left\{1 + \left(\frac{n^2 - R^2 + 1}{n^2 - R^2}\right)e^{-2Rt} - 2e^{-Rt}\sqrt{\frac{n^2 - R^2 + 1}{n^2 - R^2}}\sin \times \left[\tan^{-1}\sqrt{n^2 - R^2} - \Delta nt\right]\right\}^{\frac{1}{2}} \sin(nt + \alpha),$$

where

$$\alpha = \tan^{-1}\frac{-1 + \sqrt{\frac{n^2 - R^2 + 1}{n^2 - R^2}}e^{-Rt}\sin \times \left[\Delta nt + \tan^{-1}\sqrt{n^2 - R^2}\right]}{\sqrt{\frac{n^2 - R^2 + 1}{n^2 - R^2}}e^{-Rt}\cos\left[\Delta nt + \tan^{-1}\sqrt{n^2 - R^2}\right]}.$$

[4] Barton and Browning, "*Phil. Mag.*," 36, p. 171, 1918.

If the damping is small, the "beat" maxima occur at a comparatively late time, that is, when the free vibration has nearly died away. If the damping is large, however, these "beat" maxima occur for small values of t and should therefore be observable. Calculation shows that even though, with large damping, the free vibration decays more quickly, the maxima occur at such an early stage that the amplitude of the resultant motion is appreciably greater than the amplitude of the forced vibration in the steady state. With large damping, that is, nearly equal to, or greater than, the critical, the first maximum occurs on the first outward excursion of a mechanical system. We can not very well call these maxima "beats," although they are in every way, except in their origin, the same as "beats" and can not be distinguished from them. Beats, in the generally accepted sense of the word, are possible only in an undamped system under forcing or in systems of which the vibrations are separately maintained. The pseudo-beats observed in a damped system under forcing may have a greater or a smaller frequency than the difference between the impressed and the natural frequencies depending upon whether s is negative or positive, that is, on whether the impressed frequency is greater or smaller than the natural frequency of the system.

4. In all cases where there is damping and where s is different from Δn, the first "beat" maximum is greater than any of the later relative maxima and greater than the amplitude of the forced vibration in the steady state, while the first minimum is smaller than any later relative minimum; the maxima decrease, while the minima increase, to the amplitude of the steady state vibration.

The absence of beats is neither a sufficient nor a necessary condition for resonance in a damped system; when there are no beats this simply means that the difference between the squares of the frequencies has the critical value.

3. EXPERIMENTAL ARRANGEMENT.

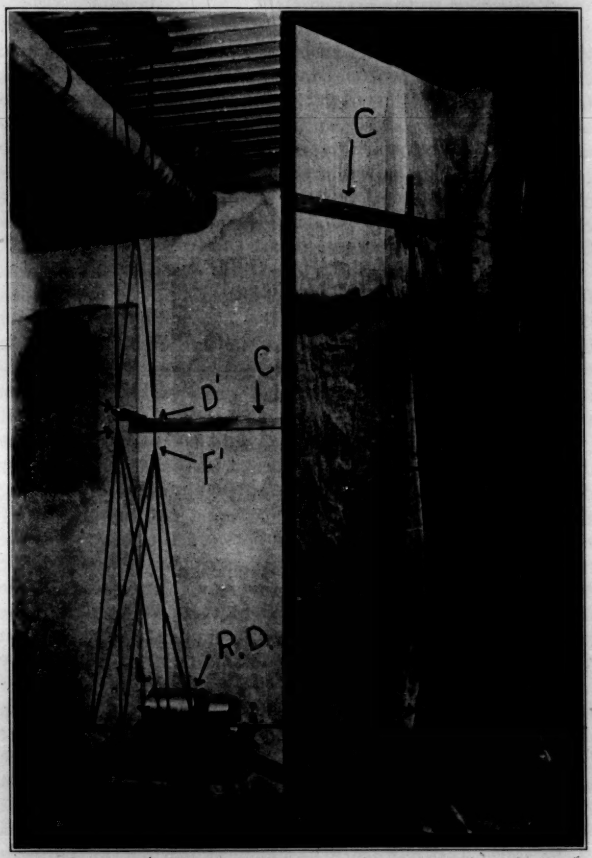
(*a*) *Small Damping:* The experimental arrangement is shown in the photograph, Plate I. A lead disc P weighing about 46 pounds was suspended from the ceiling by means of two piano wires. At the points F and F' three other wires

were soldered to these suspensions and secured to the bob as shown in the photograph to assure as great rigidity and freedom from torsional motion as possible. A photographic objective L was placed on the bob, and the light from a distant pin-hole source focused on a rotating drum $R.D$ carrying the photographic paper. This drum was set with its axis parallel to the direction of motion of the pendulum. In this manner the spot of light traversed the paper with the motion of the pendulum. A cross-piece was secured between the suspension wires at the points D and D'. Then a stick of wood C one inch square and 6.5 feet long was secured to this cross-piece and fastened by means of a brace at right angles to it. The other end of the stick C was provided with a brass knife-edge which rested in a slot N screwed to a vertical connecting rod A four feet long. The lower end of the rod A was fastened to an adjustable-eccentric bearing E in a large wooden pulley Q, while the upper end rested against a steel pulley B which permitted of adjustment in a vertical direction. The stick C was held in position against the connecting rod A by a coiled spring S secured to the wall of the room. The pulley Q was driven through appropriate pulleys and counter shaft by a one-eighth horsepower, 110 volt, direct-current motor. The motor derived its power from a bank of storage batteries, its speed being regulated by a rheostat.

It was found that the pendulum was insufficiently damped, the time required to reach the steady state being upward of an hour. Two horseshoe magnets M and M' were then placed one on each side of the pendulum bob, so that the latter oscillated between the poles of the magnets.

It is perhaps not immediately evident that with the arrangement as described and illustrated the upper extremity of the effective pendulum at D could be moved in simple harmonic motion as required by the theory. It is true that a point on a connecting rod does not execute simple harmonic motion; however, when it is remembered that the distance EN was 93 cm. (3 ft.), that the vertical distance from N to the horizontal through the center of the pulley B was never more than 15 cm., that the eccentricity of E had to be so small that the amplitude impressed at D was never greater than 0.5 millimeters and as small as approximately 0.01

PLATE I.



View of the experimental arrangement.

millimeters in this part of the experiment, there can be no valid objection to the arrangement.

Considerable difficulty was at first experienced in keeping the motor running at uniform speed. When first connected the speed of the motor was found to increase due to the rise in temperature. Whenever the batteries were connected to other apparatus in the laboratories the speed changed. By operating the motor for at least two hours before taking any records, by making sure that the batteries were not connected anywhere else, and by working at night when temperature changes were less likely to occur, the speed of the motor was finally kept sufficiently constant.

(*b*) *Large Damping:* The lead bob described above was found to be too heavy to permit of large damping. A wooden disc was then substituted for the heavy bob. A quarter inch copper plate, sixteen inches long and eight inches wide was secured to this disc in a vertical position and an electromagnet placed so that the copper plate oscillated between the pole pieces. The weight of the bob was then only eight pounds, and the damping factor could be made as large as desired. The optical arrangement was also changed by connecting an optical lever to the pendulum and focusing the light from the pinhole source on a rotating drum by means of a long-focus lens placed between the source and the mirror on the optical lever. In this manner it was possible to secure such magnification that the amplitude of the impressed force could be reduced to such a value that the pendulum never oscillated with an amplitude greater than 3 mm. The prevention of larger displacements was necessary on account of the fact that with large damping and a lighter bob the instantaneous axis of oscillation of the pendulum shifted to a point considerably below the top of the effective pendulum, thus causing a rocking motion of the bob which was objectionable. With small oscillations of the pendulum this rocking was negligible.

In this part of the work the requirements as to steadiness of the motor were not nearly as stringent as when the damping was small, and no difficulty was experienced. Different degrees of damping were secured by inserting suitable resistances in the circuit of the electromagnet.

4. EXPERIMENTAL RESULTS.

(*a*) *Small Damping:* Figures Nos. 1–18 inclusively are records of the motion of the pendulum bob under the influence of an impressed periodic force, the bob having been at rest at the beginning. In order to facilitate bringing the pendulum to rest and also to assure its being at rest when a record was started, a strap of brass *H* 3 mm. thick, 25 mm. wide and 30 cm. long was fastened in a vertical position to the lower side of the bob. A can filled with heavy oil was placed on a stool under the bob in such a manner that the oil can could be raised or lowered without disturbing the pendulum. Before starting a record the oil can was raised, immersing the brass strap in the oil to a depth of about five inches and thus bringing the pendulum to rest. When, after a few minutes, this had been accomplished, the can was lowered until the brass strap no longer dipped into the oil. A strip of photographic paper was then placed on the rotating drum and the motor connected with the system. As indicated above, the motor was never stopped between records, because, even if stopped for a very short time only, there was a slight cooling off, and consequent erratic speed.

The natural period of the pendulum was 1.708 seconds. In obtaining records Nos. 1–9 the period of the impressed force was greater than this natural period; the period of the impressed force was increased each time a new record was started. It is to be noted that the "beats" are longer on each record after the first than on the preceding record. The amplitudes also increase as resonance is approached, but the increase is much less than it would have been if the amplitude of the impressed force had been the same. As resonance was approached it became necessary to reduce this amplitude in order to keep the displacement of the pendulum sufficiently small to permit of recording, and also to prevent a change of the period and consequent error. In taking record No. 8 the amplitude was reduced to the order of 0.01 millimeters. The impressed amplitude was smaller on this record than on No. 10. Each record represents a run of approximately forty-five minutes. On No. 1 the impressed period was 1.678 seconds. As seen from No. 9, there was only one "beat" in about forty minutes.

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

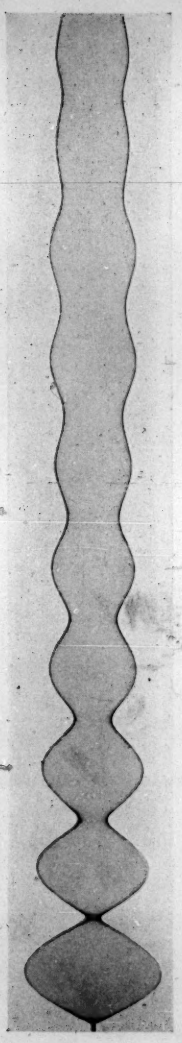


FIG. 5.

FIG. 6.

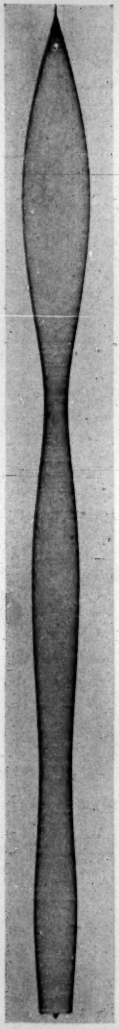


FIG. 7.

FIG. 8.

FIG. 9.

FIG. 10.

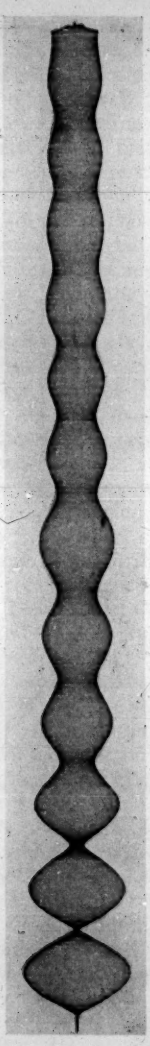


FIG. 11.

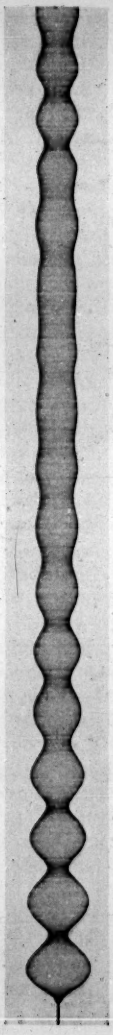


FIG. 12.

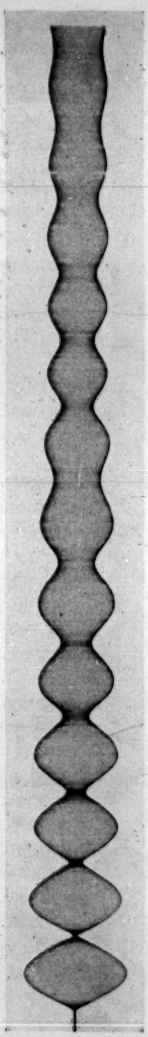


FIG. 13.

Fig. 14.

Fig. 15.

Fig. 16.

Fig. 17.

Fig. 18.

Record No. 10 shows the resultant displacement at, or very near, resonance. It is to be regretted that this record is not done as well photographically as the others, but for some unexplained reason the light was less intense while this record was being run, necessitating excessively long development and resulting in a fogged print. Many attempts were made to obtain another such record, but in vain; it was rather fortunate and somewhat accidental that the speed of the motor could be adjusted to maintain such remarkable constancy and, as near as one can tell, complete resonance. However, since the damping factor R was small, namely 0.0015, it is possible that there was a difference between the frequencies, namely the critical frequency-difference, mentioned under 2 above.

In records Nos. 11–18 the impressed frequency was still further reduced, being about as much below the natural frequency of the pendulum in No. 18 as it was above this frequency in No. 2.

The agreement with theory is truly remarkable. The first "beat" maximum is always the largest, the first minimum always the smallest. The amplitude of the forced vibration is always less than the maximum amplitude of the "beats."

In record No. 19 the pendulum was again started from rest. The speed of the motor, the amplitude of the impressed force and the damping were the same for this and the following three records. In Nos. 20, 21, and 22 different initial conditions were imposed. In each case the pendulum was caused to oscillate freely as shown at the beginning of each record. In 20 the motor was connected when the pendulum was swinging out on the right, in 21 when it was stopping at the right and in 22 when it was swinging in toward the left on the same side. There is apparently very little difference in these three records. We notice, however, that the minima in No. 20 decrease very nearly as a continuation of the decay curve of the undisturbed pendulum. In 21 the first minimum is somewhat lower than the decay curve, while the first minimum in 22 is still lower. The first maximum is greatest in No. 21, and least in 22. Remembering that the initial displacement was positive, although not exactly the same, in all three cases, that the initial velocity

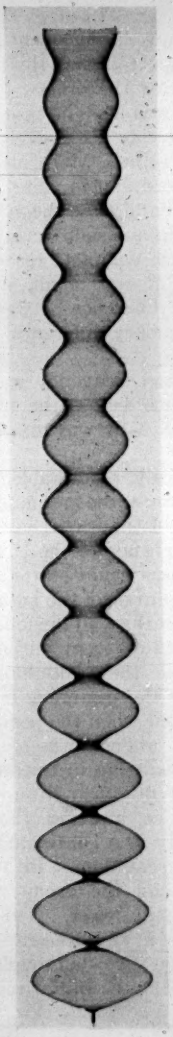


FIG. 19.

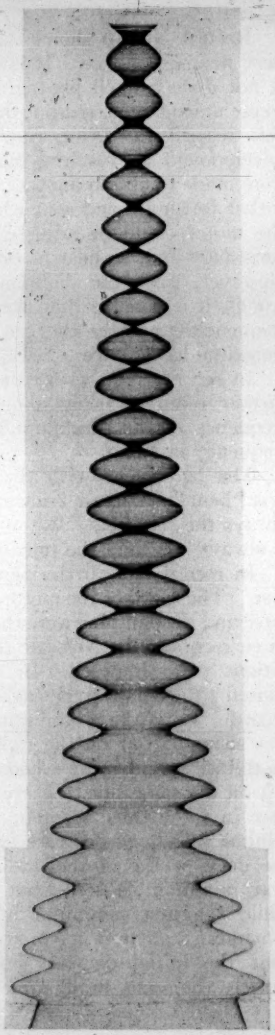


FIG. 20.

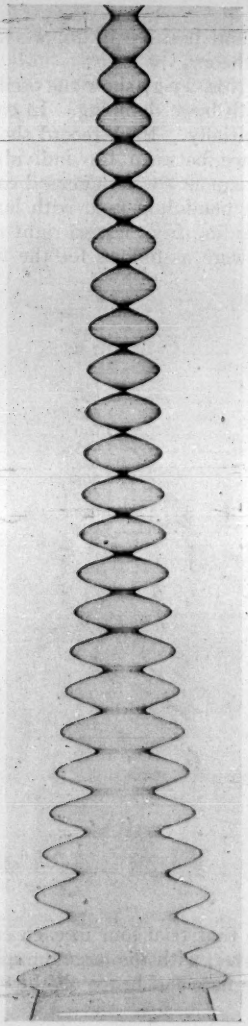


FIG. 21.

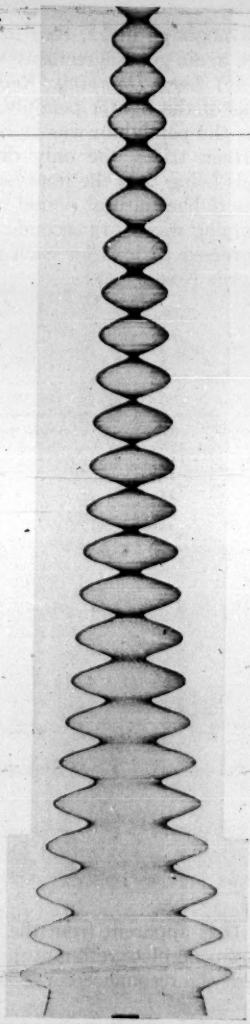


FIG. 22.

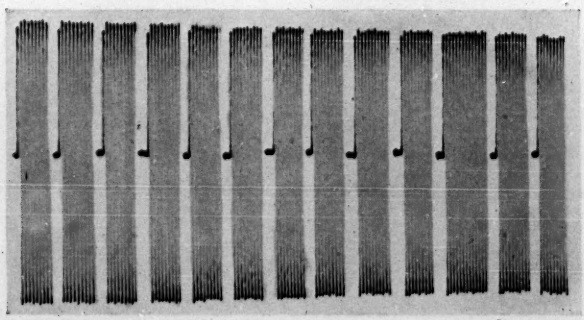
was negative in 22, zero in 21, and positive in 20, we find here again good agreement with theory.

(*b*) *Large Damping:* Records Nos. 23–27 show the oscillations of the lighter pendulum with large damping. In each case the pendulum was at rest initially. Each record shows thirteen trials, the only difference between the individual trials being that the impressed frequency was increased each time. The natural period of the pendulum used with large damping was 1.713 seconds. Reading from left to right the impressed periods for each trial were as follows for the five records Nos. 23–27:

TABLE I.

Trial	Periods (seconds)
1	1.739
2	1.730
3	1.721
4	1.713
5	1.706
6	1.698
7	1.690
8	1.683
9	1.675
10	1.667
11	1.660
12	1.652
13	1.644

FIG. 23.



It is apparent from the table that trial four in each case shows complete resonance; however, with the large damping used, the resonance curve is very flat, and hence all thirteen

trials approximate to resonance. Record No. 23 shows the resultant motion of the pendulum when the damping was such as to give the decay curve shown in the left-hand record of 23*a*. The drum was rotated faster in 23*a* than in 23 in

FIG. 23*a*.

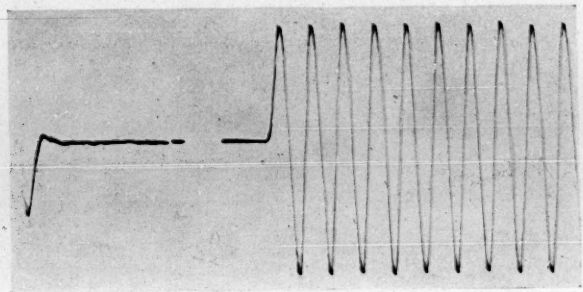
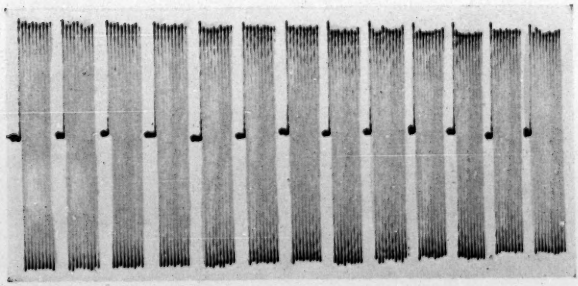


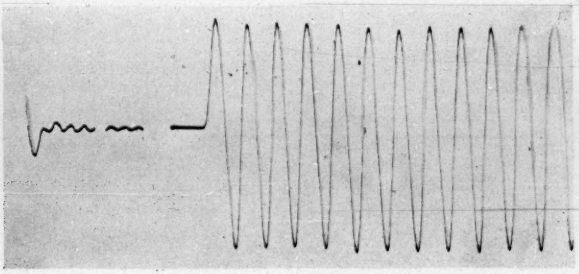
FIG. 24.



order to show better the decay curve and also, on the right-hand side, the change of phase at the beginning of the motion. When the damping is large the phase change is very rapid, being $-\frac{\pi}{2}$ in less than one period. As shown in 23*a* the drum moved forward a distance of 15 millimeters during the first complete vibration of the pendulum and 11 millimeters

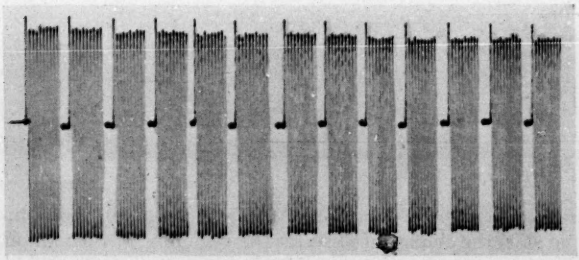
during any one complete vibration of the forced oscillations. The free vibration was practically damped out during the first period. It is to be noticed that with this damping the first outward excursion of the pendulum is less than the ampli-

FIG. 24*a*.



tude of the forced oscillations in the steady state; calculation shows that in this case the maxima are very little larger than the amplitude of the forced vibration, and they are for this reason not observable on this record.

FIG. 25.



In taking record No. 24 the damping was greater than in 23 as is shown by the decay curve on the left-hand side of 24*a*. The maximum in each trial shows up very clearly on the first swing as is required by theory.

FIG. 25a.

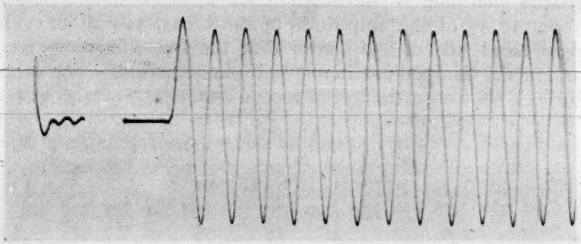


FIG. 26.

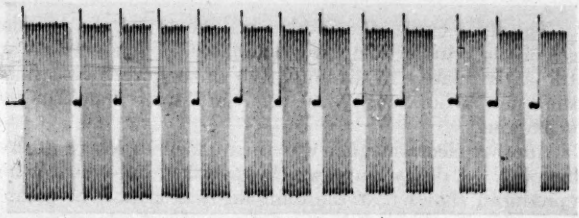
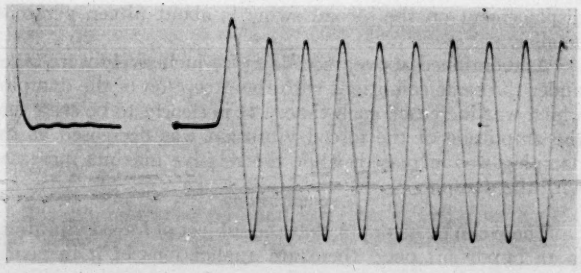
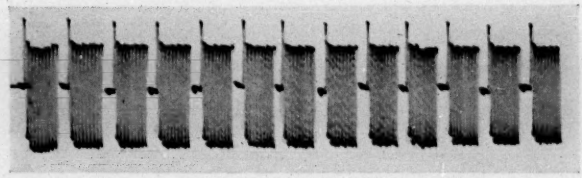


FIG. 26a.



Record No. 25 shows the resultant motion with still greater damping. The maxima are more prominent, being about 17/15 of the amplitude of the forced vibration. The right-hand side of 25*a* shows that the free vibrations were practically damped out in one-half of one period. The decay curve is shown on the left of record 25*a*.

FIG. 27.



The decay curve of record No. 26*a* shows that the damping was nearly critical when 26 was obtained. The maxima are still larger relative to the amplitude of the forced vibrations, being now about twenty-five per cent. larger than the later oscillations.

Another electromagnet was then added to secure greater damping. A decay curve which was taken but which is not reproduced shows that the damping was critical or greater than critical. Record No. 27 shows the displacements of the pendulum with this damping. The amplitude of the first swing of the pendulum is about thirty-five per cent. greater than the amplitude of the steady motion, while the displacement on the second swing is about fifteen per cent. smaller.

As mentioned above, records 23–27 inclusively were taken under the same conditions with the exception of the damping which was increased each time. It is clearly to be seen that the amplitude of the forced vibration was decreased as the damping was increased, while the relative maxima increased with the damping.

5. CONCLUSIONS.

There can be no doubt that the subject of forced vibrations is an important one; there are applications of it in nearly every branch of physics. One needs only to point out

mechanics, acoustics, optics, alternating currents in general and wireless telegraphy and telephony in particular. The subject has been investigated for a long time and has been incorporated into many textbooks dealing with differential equations and theoretical physics. The writer does not know of any intensive experimental investigations published before this; and it seems that all investigators, both theoretical and experimental, have entertained false notions about the subject. A statement by Barton and Browning to the effect that "While the free vibration is dying away, the resultant motion grows from nothing to the fixed amplitude and phase of the forced vibration" has been quoted earlier in this article. I have shown that this statement is true for one very special case only. Lord Rayleigh [5] writes: "During the coexistence of the two vibrations in the earlier part of the motion, the curious phenomenon of beats may occur, in case the two periods differ but slightly." Quite on the contrary, beats occur in every case (whether the difference between the frequencies be large or small) in which the difference between the squares of the frequencies is not equal to the square of the damping factor R; beats occur even at resonance in a damped system. The absence of beats proves conclusively that the two frequencies are different.

The first "beat" maximum is always the greatest, for at the beginning of the motion the free vibration is stronger than at any later time, while the amplitude of the forced vibration is constant. The first relative minimum occurring after the beginning is for the same reason the smallest minimum.

It is interesting to note the rôle played by the damping factor. The "beat" frequency s

$$\frac{s - \Delta n}{2\pi} = \frac{\sqrt{n^2 - R^2} - p}{2\pi}.$$

If R is zero this reduces to $\frac{n - p}{2\pi}$, and we have true beats. If R is different from zero and less than n, and if we have at the same time $R^2 \neq n^2 - p^2$, pseudo-beats always occur.

[5] "Theory of Sound," 2d ed., p. 50; Macmillan, 1894.

Hence there are "beats" even at resonance; this is amply illustrated by the results of the experiment. That the relative maxima should become larger with increasing damping seems, at first blush, strange. This is explained, however, by the change in phase which causes the period of the resultant vibration to be longer while the free vibration lasts. The rate of change of phase varies with the damping factor, the time required for the phase to become constant depending upon R and being less when R is large.

It has been shown that the oscillatory solution of the differential equation of forced vibrations should be written in the form (5) rather than in form (2) as generally given in textbooks, because the former solution exhibits more clearly the important facts. Failure to reduce the solution to form (5) has resulted in the overlooking, on the part of investigators, of many interesting facts regarding this type of motion. Physical intuition is not a sufficiently sure guide when the problem is to combine two or more oscillatory motions although, when once seen in an equation, everything shown by the mathematical solution permits of clear and simple physical interpretation.

I take pleasure in acknowledging my indebtedness to Professor Romberg for helpful suggestions.

PHYSICAL LABORATORY,
UNIVERSITY OF TEXAS,
AUSTIN, TEXAS,
March 26, 1928.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

BUREAU OF STANDARDS JOURNAL OF RESEARCH.

THERE has just been issued the first number of a new monthly periodical, the "Bureau of Standards Journal of Research." This journal continues the publication of the two series of research papers heretofore issued—"Scientific Papers" and "Technologic Papers." Forty-four volumes (22 of each of the two superseded series) have been published, comprising 942 research papers (572 on fundamental and 370 on applied science).

The new journal will contain the bureau's research papers and critical reviews in the fields of science and technology. These will be comparable in interest and importance with the scientific and technologic papers already issued. The union of pure and applied science in one journal will, it is believed tend to shorten the lag between discovery and its application.

Everyone engaged in scientific or technical work should have available for current use and permanent reference this new research journal. The paper page size is $5\frac{7}{8}$ x $9\frac{1}{8}$ inches, and each volume (semiannual) will be indexed. A cumulative consolidated index will be included in the bureau's list of publications as heretofore.

The subscription rate is $2.75 in the United States, Canada, Mexico, or Cuba, and $3.50 per year for other countries. The price of single copies is 25 cents domestic and 31 cents foreign. Remittances must be sent to the Superintendent of Documents, Government Printing Office, Washington, D. C., *not* to the Bureau of Standards.

Shortly after each month's *Journal* is published, reprints of the separate articles contained may be purchased from the Superintendent of Documents.

PHYSICAL PROPERTIES OF HEAVY CLAYS.

IN connection with the heavy clay investigation being conducted at the Columbus branch of the bureau, a series of

* Communicated by the Director.

experiments was carried out to ascertain the pressures required to extrude the several shales and clays through dies. The pressure required to cause continuous flow of the material through a die of $\frac{1}{2}$ inch diameter was determined at four different percentages of tempering water for each of the shales and clays, the values being obtained for two different finenesses of grind, namely, as ground in a commercial 5 ft. dry pan, and as ground in a ball mill for about 16 hours after dry panning. The data were plotted into curves from which the extrusion pressures could be obtained at the water concentration previously found to be necessary for properly tempering when the small auger machine was used. These values are shown in the following table.

Attention is called to the fact that the ball-milled shale samples required considerably more pressure than the commercially ground samples, the values averaging 117.9 and 25.9 lbs./in.^{2} respectively when using the same percentages of water. This is to be expected, because with a marked increase in fineness of grain greater amounts of water are required for properly tempering. In the case of the glacial and alluvial clays, the effect of ball milling was not very clear-cut because of the extreme fineness of these clays even when commercially ground. However, in general, a decrease in grain size is accompanied by a decrease in extrusion pressure when properly tempered, this being probably due to lessened friction. This is shown by the fact that even when using the same percentages of water, the average pressures for the commercially ground and ball-milled glacial clays are 56.2 and 54.7, respectively. In the case of the alluvial clays, the average pressures for the commercially ground and ball milled samples are 85.1 and 82.4, respectively.

Slight variations in water content greatly affect the extrusion pressures. Thus, it is evident that in the industry great fluctuations in the power required for the pug mill and auger machine may be encountered by slight variations in the amount of tempering water employed and by the fineness of the grind. In general, alluvial clays require greater extrusion pressure than glacial clays, and shales require less than either of the clays, the average values being 90.5, 56.2, and 25.9 lbs./in.^{2} respectively.

	Kind of Shale or Clay.	Pressure in Pounds per Square Inch Required to Extrude through a ½ Inch Diameter Die.	
		Commercial Grind.	Ball Milled.
Shales	Allegheney, Malvern	31.2	262.0
	Connemaugh, Ava	15.0	199.0
	Allegheney, New Lexington	20.0	76.5
	Waverly, Hanover	29.5	31.5
	Chagrin, Cleveland	17.0	41.2
	Waverly, Portsmouth	27.0	110.0
	Dunkard, Marietta	10.0	191.2
	Pottsville, Portsmouth	45.0	88.0
	Connemaugh, Summitville	13.0	83.7
	Bedford, Columbus	24.5	63.5
	Cincinnati, Cincinnati	52.5	150.5
Glacial	Lima	74.0	80.0
	Findlay	46.2	48.0
	Upper Sandusky	72.5	91.2
	New London	56.7	53.0
	Mt. Healthy	23.2	19.0
	London	51.2	48.5
	Toledo	70.0	43.0
Alluvial	Sugar Creek	41.5	49.5
	Westerville	75.0	75.2
	Beaver	79.5	83.7
	Zanesville (loess)	50.5	51.7
	Gallipolis	128.7	112.0
	Zanesville	135.7	122.5

Same amounts of water used for each clay or shale in commercial grind and ball milled.

PHYSICAL PROPERTIES OF BODIES COMPOSED OF POTTER'S FLINT AND CLAY.

The china clay investigation in progress at the Columbus branch of the bureau includes a study of the clays in bodies as well as a study of the clays alone. The composition of one set of bodies is 50 parts potter's flint and 50 parts clay, while the other is 50 parts clay, 30 potter's flint, and 20 feldspar. It is believed that the real reasons for the differences in the clays will be brought out more clearly by studying the reactions when in bodies as well as when treated individually. The general purpose of the investigation is to compare English and American china clays, but as yet only the English have been studied. Of these, seventeen commercial brands are being used. During the past few months the work on the

bodies composed of potter's flint and clay was carried out and is nearly completed.

Each of the clays was made up with an equal weight of potter's flint into a body; the size of specimens and procedure of making and testing following closely the specifications of the American Ceramic Society. The properties evaluated on the unfired bodies were those of volume shrinkage, shrinkage water, pore water, water of plasticity, bulk specific gravity, slaking time, and modulus of rupture. On the fired bodies values for volume shrinkage, porosity, bulk specific gravity, and modulus of rupture were determined at seven different temperatures namely, cones 3, 5, 8, 11, 14, 18, and 23.

The various bodies have so nearly the same value for any one property that for the present purpose, averages only are given. To show the effect of the flint, general averages for the clays alone are also given.

Dry Properties of Clays and Bodies.

Material.	Properties.						
	Volume Shrinkage.	Shrinkage Water.	Pore Water.	Water of Plasticity.	Bulk Specific Gravity.	Slaking Time.	Modulus of Rupture.
	per cent.	per cent.	per cent.	per cent.		hours.	lbs./in.[2]
Clays alone	18.6	11.6	29.8	41.3	1.46	7.7	88.0
Bodies	11.6	7.1	20.4	27.5	1.64	6.6	46.6

Fired Properties of Clays Alone.

Property.	Cone.						
	3	5	8	11	14	18	23
Volume shrinkage [1]	20.0	26.3	32.5	41.7	48.8	48.5	48.5
Porosity [1]	40.3	35.9	29.0	17.5	3.9	1.2	1.0
Bulk specific gravity	1.60	1.75	1.91	2.17	2.45	2.50	2.50
Modulus of rupture [2]	—	—	2,200	3,000	4,000	5,500	6,000

[1] Values in per cent.

[2] Expressed in lbs./in.[2]

Fired Properties of Bodies.

Property.	Cone.						
	3	5	8	11	14	18	23
Volume shrinkage [1]	7.3	8.4	9.6	12.2	17.8	26.2	31.1
Porosity [1]	34.9	34.3	33.7	33.7	26.4	15.7	2.7
Bulk specific gravity	1.64	1.66	1.68	1.72	1.83	2.06	2.21
Modulus of rupture [2]	35	450	765	890	1,350	2,000	2,600

UNSLAKABLE RESIDUE IN QUICKLIME.

HYDRATED lime is produced from quicklime by treating quicklime with water in one of several different methods. The hydrate produced is usually in a very fine state of subdivision, however, to insure a uniformly fine product it is common practice to separate the fine material from the coarse by a process of air separation. Occasionally it is found that an undue amount of coarse residue is obtained. When the amount is large it represents a considerable loss to the producer of the lime, and it is consequently desirable to reduce the amount of residue to a minimum.

As it was considered of general interest and value to lime producers, the bureau has investigatetl the nature of unslakable residues. A sample of quicklime known to give considerable residue and a sample of the stone from which the quicklime was made were obtained. A weighed amount of the quicklime was added to a slight excess of water, stirred until slaking was complete, and then washed by decantation until the water ran clear. This process produced a residue which was dried in an oven at 110° C. and then weighed. It was found that the method gave about 5 per cent. residue in the form of hard gritty lumps, the largest of which were approximately one-eighth inch in diameter. This was ground in a mortar until it passed a No. 200 sieve. It was then analyzed by the method outlined in Bureau of Standards Circular No. 204.

Samples of the stone and of the quicklime were also analyzed by the same methods. SO_3 determinations were

[1] Values in per cent.

[2] Expressed in lbs./in.^{2}

made on all three materials by the methods given in Bureau of Standards Circular No. 33. The following results were obtained. They have been calculated to the non-volatile basis.

Determination.	Stone.	Quicklime.	Residue.
SiO_2	.97	1.00	3.08
R_2O_3	.25	.36	.79
CaO	98.20	97.80	80.90
MgO	.45	.53	15.45
SO_3	None	Trace	Trace

It is evident that the silica is somewhat concentrated in the residue. It is also evident that the greater part of the MgO from the stone has concentrated in the residue.

From the limited data it is impossible to draw any generalizations. It is hoped that future work on this subject may result in some conclusions which will be helpful in eliminating this undesirable waste in hydrated lime production

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REMOVAL AND EXAMINATION OF SOIL-CORROSION SPECIMENS.

THE plans of the Bureau of Standards soil-corrosion investigation call for the removal of parts of the specimens at two-year intervals. In accordance with these plans the work of removing specimens of iron and steel pipe and lead cable sheath which have been buried for six years is well under way and will be completed during the present month. The specimens are returned to Washington where they are cleaned and the rate of corrosion and pitting determined. The specimens are then photographed and stored. About 1,000 specimens will be removed this year.

A report on the results of the 1928 examination will be available early next year.

The Bureau recently issued its first report on its soil-corrosion work as Technologic Paper No. 368, "Bureau of Standards Soil-Corrosion Studies. I. Soils, Materials and Results of Early Observations." Owing to the demand for this publication the Bureau's supply for official distribution has been exhausted, but it can be secured from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 50 cents per copy.

This investigation was begun in 1922 as a supplement to the study of corrosion due to stray electric currents. It had become evident that in some cases where serious corrosion had occurred the cause of the corrosion could not be definitely determined until it was known whether such corrosion could occur in natural soils where no stray currents were present. The original investigation was therefore quite limited in its scope. The results obtained soon showed beyond question that corrosion of metal structures in soils was an extremely important problem in itself. Incidentally some other tests have shown that the processes of corrosion may include the production of rather large electric currents in pipe lines even when there are no extraneous sources of current.

A very wide interest has been manifested in soil corrosion, and many questions have been raised which can not be answered by the data which are being obtained. The work will not be finished for several years, but because of the interest manifested and the plans for corrosion studies that other organizations are considering, it has seemed advisable to set forth in some detail the plans and scope of the bureau's investigation and to publish and discuss such data as are now available as a result of the investigation. The data indicate that in certain regions soil corrosion is an active enemy of buried pipe lines, that the material best suited to resist the action of one soil is not necessarily the best for other soil conditions, and that the use of some form of a protective coating is desirable under a number of soil conditions.

Because the rates of corrosion so far observed may not continue and because the rate for one material may change more than the rate for another, no conclusions can be drawn at this time as to the ultimate life of any of the materials under test nor of the relative merits of materials that are nearly alike. So far as observations on the materials are concerned, the report given in Technologic Paper No. 368 is therefore preliminary in its nature.

EFFECT OF RELATIVE HUMIDITY AND TEMPERATURE UPON THE PHYSICAL PROPERTIES OF VULCANIZED RUBBER COMPOUNDS.

The work of the Physical Testing Committee, Rubber Division, American Chemical Society, carried on at the

bureau during the last year, in which the effect of temperature and humidity upon the stress-strain relation, both subsequent and prior to vulcanization, was investigated, will soon be published in *Industrial and Engineering Chemistry*. Several thousand tests were made covering a range of relative humidity from 0 to 100 per cent. and a range of temperature from 5 to 45° C. These ranges were covered with 5 compounds and each compound was represented by a range of 5 cures.

The work is now being extended with three of the compounds used previously, and an additional one which simulates a commercial heel compound, in a study of resistance to abrasion. This resistance to abrasion is being determined over a range of temperatures and humidities. The investigation is only partially completed, but it has been found that a difference of 20° C. may cause a 25 per cent. change in resistance to abrasion. This difference due to temperature varies both in degree and kind with the compound used.

Measurements of resistance to abrasion are being made in each case with two machines of quite different types. The Grasselli instrument, which works on the Prony brake principle, gives results in volume abraded against an emery paper, per horsepower hour, while the U. S. machine records the volume abraded per hour by a wheel bound with emery cloth, with no power measurements taken.

PERMANENCE OF BOOK PAPERS.

THE Bureau of Standards has recently initiated, as a part of its general study of the permanence of paper, research on the permanence of book papers. This particular line of investigation was taken up for two reasons. One is to make certain that the paper used for the research publications of the Bureau will have the desired permanence. The other is on account of the rapidly increasing interest in general in preservation of printed matter of permanent value. An illustration of this interest is the recent development, in which the Bureau coöperated, of a newsprint paper made of rag fibers for printing special permanent issues, of newspapers for libraries. Such issues are being made by a number of publishers.

There is interest in a similar project, especially on the part of the American Library Association, for books and other bound printed matter.

The immediate work planned is the testing of products on the market at the present time. These will include complete chemical and physical tests to find the composition of the papers, accelerated aging tests made by exposure to heat and light, studies of the effect of the constituents of the papers on their permanence, and coöperative work with manufacturers to correct any properties of the papers that may be found undesirable from a permanence viewpoint.

VAPOR LOCK IN AIRPLANE FUEL SYSTEMS.

EXPERIENCE in the altitude chamber of the Bureau of Standards indicates that occasional engine failures and more frequent erratic performance of airplane engines are caused by the permanent or temporary interruption of normal fuel flow due to the formation of gas bubbles in the carburetor jet or elsewhere in the fuel system. This difficulty is known as "vapor lock" and is most likely to occur with fuels containing an excess of the more volatile constituents or of dissolved gases.

The provision in the present aviation gasoline specifications which says that the 5 per cent. point on the American Society for Testing Materials distillation curve shall not be lower than 50° C. (122° F.) was placed there as a protection against vapor lock. It is believed, however, that this particular limitation on the volatility of aviation gasoline excludes some gasolines which are not likely to cause vapor lock admits others which are liable to cause vapor lock.

A study of aviation gasolines is now in progress at the Bureau, with the object of developing means of distinguishing between fuels which are suitable for use in airplane engines and those which are unsuitable from the point of view of possible difficulty from vapor lock.

THERMAL EXPANSION OF MAGNESIUM AND SOME OF ITS ALLOYS.

AN investigation on the linear thermal expansion of pure magnesium, magnesium-aluminum alloys, and magnesium-

aluminum manganese alloys has recently been completed. Magnesium, the lightest structurally used metal, and its alloys, are becoming more prominent for materials of construction where lightness and strength are important factors, for example in aircraft manufacture and for moving parts of gasoline engines.

Expansion determinations were made on six samples of cast and extruded magnesium and 11 samples of cast and extruded magnesium alloys. The samples of magnesium were investigated over various temperature ranges between − 183 and + 500° C. and most of the alloys between room temperature and 300° C. Three types of expansion apparatus were used in this investigation. The average coefficient of expansion of pure magnesium was found to be 0.0000260 per °C. between 20 and 100° C.

The results obtained will be published by the Bureau of Standards. The publication will also include a summary of available data by previous observers on the thermal expansion of magnesium and a few magnesium alloys, and a figure which shows the relations between the chemical composition and the coefficients of expansion of the magnesium alloys.

Copies of the publication will be available in a few months.

RADIO AIDS TO AIR NAVIGATION.

RESEARCH work extending over two years has resulted in the development and practical demonstration of radio aids to flying on the civil airways. These aids comprise a radio beacon system marking out definite courses, and radio telephone service from ground to airplane. The whole system can be utilized by airplanes carrying no radio apparatus except a simple receiving set. This development, which was carried on by the Bureau of Standards for the Aeronautics Branch of the Department of Commerce, was briefly described in the Radio Service Bulletin, March 31, 1928, on page 19. A technical description of the work, "Development of Radio Aids to Air Navigation," by J. H. Dellinger and Haraden Pratt, was published in the *Proceedings of the Institute of Radio Engineers*, July, 1928, page 890.

In the same issue of the *Proceedings*, page 985, there is

given a "Bibliography on Aircraft Radio," by C. B. Joliffe and Elizabeth Zandonini. This bibliography includes 257 references to foreign and domestic periodicals.

Copies of these two reports are not available from the Government. A copy of the *Proceedings of the Institute of Radio Engineers* may be obtained from the Institute at 33 West 39th Street, New York, N. Y., for $1.

A Pitcairn Mailwing airplane was put at the disposal of the bureau by Pitcairn Aviation, Inc., for the installation of radio receiving equipment including the visual indicator. This airplane is to be used later by this company in its regular air mail service from New York to Atlanta which passes through Washington, and will make use of the College Park beacon. This will give a test of the beacon system under actual conditions of use. The high tension ignition system of this airplane was completely shielded, the leads from the magneto distributor blocks to the spark plugs were replaced by shielded high tension cable drawn through the conduit manifold rings, shielding plates put over the magneto distributor blocks, and the spark plugs covered by special caps.

Several long flights were made by this airplane in order to test the radio installation on the plane and the operation of the beacon. On one flight a range of 90 miles was obtained through severe atmospheric disturbances. In another test working reed deflections were obtained at Hadley Field, New Brunswick, N. J., using the College Park beacon.

A new Fairchild cabin airplane having a capacity of four passengers was delivered and will be used for experimental work. Ignition shielding is being installed, and the airplane will be completely equipped with radio apparatus and will constitute a flying radio laboratory.

SOME RECENT ACTIVITIES OF THE COMMERCIAL STANDARDS GROUP.

Photographic Paper.—A meeting of the simplified practice committee of manufacturers of photographic paper was held in New York on July 23, to consider the program for the simplification of photographic paper of various kinds which the committee has been developing for some time. It is

expected that the final meeting of the committee will be held this month, when the schedule of sizes will be completed, in preparation for a general conference of all interests.

Lead Pencils.—The final schedule for the simplification of lead pencils has been approved and will be placed before the industry for acceptance in the near future.

Luggage.—A member of the staff has been invited to address the Luggage Dealers Convention in New York City on August 17 on the subject "Standardizing Luggage Sizes." The National Luggage Dealers Association has worked out a suggested list of sizes for the consideration of the luggage industry, covering trunks, suit cases, hat boxes, etc. It is the opinion of some that if the industry can arrive at a standardization of sizes, it will be of great economic value to both the manufacturer and retailer.

Ice Cream Cans.—The Committee on Simplified Practice of the International Association of Ice Cream Manufacturers, in conjunction with representatives of ice cream can manufacturing companies, met June 6, 1928, in New York City, to further the program of can standardization. A display of ice cream cans now being manufactured enabled the members of the committee to compare the different types and sizes of cans and determine upon tentative standard sizes. It was recommended that these sizes be submitted at the annual convention of the International Association of Ice Cream Manufacturers at Cleveland, during the week of October 18 for consideration and criticism. When the standard sized cans are finally adopted by manufacturers, distributors, and users, it will eliminate the confusion now existing because of the many types and sizes of cans on the market, and will result in a lower production cost.

Glass Containers for Drug and Pharmaceutical Industry.—At a preliminary conference of representatives of the drug and pharmaceutical industry and the Glass Container Association held July 6, a motion was presented and unanimously carried that a joint standardization and simplification committee be appointed to consist of one voting delegate and two associate delegates from each of the National Drug and Pharmaceutical Associations and the Glass Container Association of America in coöperation with the United States Department of Com-

merce, for coördinating the efforts of the various groups concerned in the simplification and standardization of glass containers used in the drug and pharmaceutical industries.

It was also the sense of the meeting that the appointment of the committee be completed as soon as possible with the view of holding its first meeting during the week of August 6 for the purpose of organization and that this first meeting be held at the Department of Commerce under the auspices of the division of simplified practice.

In accordance with the action taken at the conference on July 6 the Bureau invited seventeen different drug and pharmaceutical associations and the Glass Container Association to send three delegates to a conference at the Department of Commerce on August 10, to complete organization of a central simplified practice committee and to discuss the question of variety surveys.

Glass Containers for Jelly and Preserves.—A general conference to discuss the simplification of jelly glass and preserve jar sizes and capacities has been postponed until some time in September. This conference will be held in Washington in conjunction with the mid-year convention of the National Preservers Association.

Type Faces.—For several months the United Typothetæ of America and the division of simplified practice have been coöperating in an effort to ascertain the views of leading printers and manufacturers of type as to the advisability of inaugurating a simplification program to reduce the excessive variety of type faces. While there are conflicting opinions regarding the matter, a large majority are nevertheless in favor of a conference to discuss the subject and to formulate some plans whereby the elimination of undesirable type faces might be brought about. At the request of the United Typothetæ of America, the division of simplified practice will arrange for a preliminary conference in the fall to consider the subject of simplification of type faces. In the meantime the division will be glad to receive any comments or suggestions which the readers of this bulletin may care to express on this subject.

Hospital Plumbing Fixtures.—A tentative simplified practice recommendation for hospital plumbing fixtures has been

worked out by the manufacturers of vitreous china, porcelain, and enameled fixtures. This recommendation is now in the hands of the standardization committee of the American Hospital Association for review and further recommendation as to definite types and sizes to be used as standard items for various purposes. After the hospital authorities have compiled their criticisms and comments, there will be joint meeting of the hospital plumbing fixture manufacturers and members of the standardization and simplification committee of the Hospital Association to develop a final recommendation covering types, sizes, dimensions, etc.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

MOTION PHOTOMICROGRAPHS OF THE PROGRESS OF DEVELOPMENT OF A PHOTOGRAPHIC IMAGE.[1]

By C. Tuttle and A. P. H. Trivelli.

In the photomicrography of silver bromide grains during photographic development, high magnification and higher resolution are necessary to make the changes visible. In this work an oil immersion lens was used. The material to be photographed was coated on the under side of a microscope cover glass and the dilute developer was placed on the substage condenser. A convenient method of focusing and viewing the image is described. Two illustrations taken from the motion picture record of development are included.

THE REPRODUCTION OF MOBILITY OF FORM AND COLOR BY THE MOTION PICTURE KALEIDOSCOPE.[2]

By L. A. Jones and C. Tuttle.

By combining a kaleidoscopic prism with a suitable motion picture camera it is possible to make motion pictures in color which show the changing patterns produced when a suitable grouping of colored elements is moved slowly past the end of the prism. Such color film may be used in the theater for the embellishment of the motion picture program. A description is given of an instrument constructed for making such film by the two-color process. This consists essentially of a standard Bell & Howell camera to which is added a suitable holder for the two-color taking filters, a kaleidoscopic prism, a pattern

* Communicated by the Director.

[1] Communication No. 341 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.* 33: 157. 1928.

[2] Communication No. 354 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.*, 33: 140. 1928.

plate of colored gelatin designs on glass, a lamp for illuminating the pattern plate, and the mechanical means for driving the various elements in synchronism. Diagrams are shown illustrating the various types of symmetrical, quasi-symmetrical, and unsymmetrical patterns formed by the use of various types of prisms. The paper is illustrated by a reel of film showing both the form and the color sequences obtainable.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY AND SOILS.*

BIOLOGICAL VALUES OF CERTAIN TYPES OF SEA FOODS.[1]

III. VITAMINS IN CLAMS.

By D. Breese Jones, E. M. Nelson, and J. C. Murphy, with the coöperation of J. P. Devine.

[ABSTRACT.]

IN feeding experiments with albino rats two species of clams were used, *Venus mercenaria*, commonly known as "hard-shell clams" or "quahaugs" and *Mya arenaria*, commonly called "soft-shell clams." Both species contain little, if any, vitamin B. Soft-shell clams were found to be a somewhat better source of vitamin A. No difference was observed with respect to vitamin D.

Five grams daily of soft-shell clams, equivalent to 1 gram of dry material, was sufficient for the cure and prevention of xerophthalmia. A little more of the hard-shell clams was required. Five grams of either species given daily to rachitic rats induced complete calcification in the small bones in 15 days. The rate of calcification was not appreciably influenced by the ash constituents of the clam.

Compared with oysters, which are rich in vitamin B, clams are practically devoid of this vitamin. As a source of vitamin A clams are somewhat inferior to oysters, but they have more vitamin D, and are a better source of the factor, or factors, essential for reproduction and rearing of young.

STUDIES ON GOSSYPOL.[2]

IV. APOGOSSYPOL.

By E. P. Clark.

[ABSTRACT.]

WHEN treated with 40 per cent. sodium hydroxide at the temperature of the steam bath for half an hour gossypol is

* Communicated by the Chief of the Bureau.

[1] Published in *Ind. and Eng. Chem.*, 20: 648, June, 1928.

[2] Published in *J. of Biological Chemistry*, 78: 159–166, June, 1928.

converted into formic acid and apogossypol, a new phenolic substance, in the proportion of 2 mols of formic acid to 1 mol of apogossypol.

Apogossypol, which has the molecular formula $C_{28}H_{30}O_6$, is formed by the elimination of the two carbonyl groups of gossypol as formic acid. All the 6 oxygen atoms of apogossypol are present as hydroxyl groups. The phenol accordingly forms a hexaacetyl derivative and a hexamethyl ether by the replacement of the hydroxyl hydrogens by acetyl and methyl radicals. In the hexaacetate, as in hexaacetyl gossypol, two of the acetyl groups are more resistant to hydrolytic agents than the remaining four. The direct determination of the methoxy groups in the hexamethyl ether could not be made as the material was entirely inert in boiling hydriodic acid as used in the Zeisel method.

The toxicity of apogossypol was determined and compared with that of gossypol. Of the two, apogossypol was considerably less toxic. The lethal dose, given intraperitoneally to white rats, was found to be from 60 to 75 mg. per kilo of body weight. The physiological action of apogossypol is in sharp contrast with that of gossypol as no chronic toxic effects follow the administration of small doses.

RESINS FROM CHLORINATED CYMENE.[3]

By P. H. Groggins.

[ABSTRACT.]

CHLORINATED resin of a new type was prepared from p-cymene by chlorination in the presence of a metal catalyst. Varieties of the resin can be obtained by previously incorporating other soluble and miscible materials with p-cymene. The resins are insoluble in acids, alkali, and alcohol, and they can not be brought to the infusible state by heat and pressure treatment. The intermediate compounds have toxic properties and are lethal to small animals and to vegetable organisms.

[3] Published in *Ind. and Eng. Chem.*, 20: 597, June, 1928.

INSECTICIDAL ACTION OF SOME ESTERS OF HALOGENATED FATTY ACIDS IN THE VAPOR PHASE.[4]

By R. C. Roark and R. T. Cotton.

[ABSTRACT.]

THE action of the esters of some of the halogenated fatty acids in the vapor phase upon insects was tested. From the standpoints of toxicity to insects, availability, cost, and freedom from fire hazard, methyl, isopropyl, and ethyl monochloroacetates appear to be the most promising of the lower alkyl esters of chloroformic (chlorocarbonic), monochloro-, dichloro-, and trichloroacetic, monobromoacetic, alpha-bromo- and beta-bromopropionic and beta-chloropropionic acids tested. Dosages of 1 pound of methyl monochloroacetate, 1.5 pounds of isopropyl monochloroacetate, and 2 pounds of ethyl monochloroacetate per 1,000 cubic feet were effective against stored-product insects in fumigation vaults of the commercial type. As further tests, however, showed that the monochloroacetates injure the germination of wheat, these fumigants do not look promising for the fumigation of grain intended for seed.

AN OBSERVED CASE OF "SPONTANEOUS" IGNITION IN STABLE MANURE.[5]

By L. H. James, G. L. Bidwell, and R. S. McKinney.

[ABSTRACT.]

OBSERVATIONS were made upon a large pile of heating stable manure and straw at the Arlington Experiment Farm, Rosslyn, Va. Within a period of three days several different parts of the stack ignited spontaneously. Readings showed that in the center of the pile and up to within 5 or 6 feet of the outer surface the temperatures were not extremely high, 66° being the maximum, whereas within 6 inches of the surface the temperatures were much higher, averaging 80° C. In the loosely packed manure on the top, the maximum temperature was from 1½ to 2 feet from the surface. When exposed

[4] Published in *Ind. and Eng. Chem.*, 20: 512–514, May, 1928.

[5] Published in *J. Agr. Res.*, 36: 481–485, March, 1928.

to the air, charred straw glowed a fiery red. Oxygen aëration of a small section of the heating material produced a rapid increase in temperature of 26.5° C. in 30 minutes.

STUDIES ON GLUTELINS.

IV. THE GLUTELINS OF CORN (ZEA MAYS).[6]

By D. Breese Jones and Frank A. Csonka.

[ABSTRACT.]

CORN (*Zea Mays*) contains two glutelins (α- and β-) which are precipitable from alkaline solution by the addition of ammonium sulphate to 3 per cent. and 16 per cent. of saturation, respectively.

Analyses of the α-glutelin by the Van Slyke method showed the following composition: Amide N, 7.73 per cent.; cystine N, 2.04 per cent.; arginine N, 15.11 per cent.; histidine N, 2.81 per cent.; lysine N, 7.99 per cent.; amino N in filtrate from bases, 59.64 per cent.

The isoelectric point of the α-glutelin was found to be at pH 6.45.

SPECTROPHOTOMETRIC DETERMINATION OF HYDROGEN ION CONCENTRATIONS AND OF THE APPARENT DISSOCIATION CONSTANTS OF INDICATORS.

V. FAST GREEN F C F.[7]

By W. C. Holmes and E. F. Snyder.

[ABSTRACT.]

SPECTROPHOTOMETRIC data are supplied for the determination of hydrogen ion concentrations over the pH range between 6.7 and 10.0 with Fast Green F C F. The apparent dissociation constant of the dye in this range is approximately 8.1 (5) at 29°. Within the range of pronounced acidity the dye proves a less sensitive indicator than do the sulphonephthaleins.

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[6] Published in *J. Biological Chem.*, 78: 289–292, July, 1928.

[7] Published in *J. Amer. Chem. Soc.*, 50: 1907–1910, July, 1928.

THE FLAVOR OF MAPLE SIRUP.[8]

By E. K. Nelson.

[ABSTRACT.]

INVESTIGATION of the flavor of maple sirup showed that it depends to a great extent on an unstable phenolic substance which is associated with a crystalline aldehyde melting at 74–76° and similar in odor and properties to vanillin. Maple sirup may contain minute quantities of other aldehyde substances which influence the flavor.

THE ACIDS OF MAPLE SUGAR "SAND."[9]

By E. K. Nelson.

[ABSTRACT.]

THE acids of maple sugar "sand" were separated and identified. In addition to l-malic acid, formic, acetic, fumaric, succinic, and citric acids were found. There was evidence of traces of α-tartaric and tricarballylic acids. A small quantity of an unknown acid represented by a hydrazide melting at 173–175° was found.

THE ACIDS OF MAPLE SIRUP.[10]

By E. K. Nelson.

[ABSTRACT.]

MAPLE sirups from Vermont and from Michigan were analyzed to determine the acids. In addition to malic acid, which predominates, formic, acetic, and citric acids were identified. Also, a small quantity of fumaric acid and a trace of succinic acid were found. There was evidence of the presence of a small quantity of an unidentified acid having a high melting point. Neither α-tartaric acid nor tricarballylic acid could be found.

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[8] Published in *J. Amer. Chem. Soc.*, 50: 2009–2012, July, 1928.
[9] Published in *J. Amer. Chem. Soc.*, 50: 2028–2031, July, 1928.
[10] Published in *J. Amer. Chem. Soc.*, 50: 2006–2008, July, 1928.

THE ACIDS OF FIGS.[11]

By E. K. Nelson.

[ABSTRACT.]

ACETIC and citric acids were found in Adriatic figs; acetic, citric, and a small quantity of malic acids were identified in Calimyrna figs. The Adriatic black neck figs contained more than 10 times as much acetic acid as did the normal Adriatic figs, and less citric acid was found in them than in the normal figs. Normal Calimyrna figs contained 0.26 g. per kilo of free acetic acid and 3.5 g. of citric acid, besides a small quantity of malic acid. In Calimyrna figs affected with internal rot the free acetic acid amounted to 0.56 g. per kilo, and the citric acid amounted to 3.3 g. per kilo.

THE VALUE OF INERT GAS AS A PREVENTIVE OF DUST EXPLOSIONS IN GRINDING EQUIPMENT.[12]

By Hylton R. Brown.

[ABSTRACT.]

THE records for a 20-year period show that in feed grinding plants alone the 30 principal explosions caused the loss of 60 lives, injury to 118 persons, and property damage amounting to approximately $5,000,000. Eighteen of these explosions originated in the grinding equipment where it was impossible to prevent the formation of dust clouds or to eliminate sources of ignition. Experiments conducted by the Bureau of Chemistry and Soils have shown that it is practicable to use inert gas for flooding the inclosures of the grinding equipment and diluting the oxygen content to such a point that fires or explosions can not take place. The results of this investigation are described in United States Department of Agriculture Technical Bulletin 74.

This bulletin describes the experimental plant, the equipment used, and the tests conducted to determine the value of inert gas in preventing explosions. It discusses the effect of

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[11] Published in *J. Amer. Chem. Soc.*, 50: 2012–2013, July, 1928.

[12] United States Department of Agriculture Technical Bulletin 74. Issued June, 1928.

the gas on employees, and on the material ground, the quantity of flue gas required, and the equipment necessary. It gives directions for designing and installing an inert gas system, both where the flue gas is available and where it must be obtained from gas-producing apparatus, including a discussion of the normal air requirements, the necessary reduction of oxygen, the oxygen percentage of gas, the quantity of gas required, the quantity of gas available, and the gas-conditioning and the gas distributing equipment.

THE COMMERCIAL PRODUCTION OF SAUERKRAUT.[13]

By Edwin LeFevre.

[ABSTRACT.]

UNITED STATES Department of Agriculture Circular 35 describes the commercial production of sauerkraut. Sauerkraut is shredded cabbage which has undergone a lactic fermentation in a brine made from its own juice by the addition of salt. It should be made from the slow-growing, solid-headed varieties of cabbage, which should be fully mature before harvesting. The cabbage should be cut in shreds about as thick as a dime, and salted with about 2½ pounds of salt for each hundred pounds of cabbage. The finished product should be crisp and as free from color as possible, and should have an acidity of not less than 1.5 per cent. and preferably nearer to a maximum of about 2 per cent., calculated as lactic. Pure cultures of the fermenting organisms may be of some benefit in sauerkraut manufacture, but have not yet proved practical in commercial production or an improvement that warrants the time and expense required for their introduction. The most favorable temperature for the start of the fermentation is about 86° F. In places where the temperature is much colder than this when the cabbage is harvested and sliced, steam heating the cabbage is advisable to promote rapid fermentation to a maximum acidity.

This circular contains suggestions for the construction of a

[13] United States Department of Agriculture Circular 35. Issued June, 1928.

factory, considers the bacteriology of sauerkraut production, discusses the factors that influence quality, describes the processes of manufacture and the methods of marketing, the sanitary measures required, the desirability and methods of canning as compared to marketing in bulk, and includes an abstract of the Federal regulations governing the manufacture and sale of sauerkraut.

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BOOK REVIEWS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 285. A Study of Wing Flutter, in three parts, by A. F. Zahm and R. M. Bear. 28 pages, illustrations, quarto. Washington, Government Printing Office, 1928, price 15 cents.

Part I describes vibration tests, in a wind tunnel, of simple airfoils and of the tail plane of an MO-1 airplane model; it also describes the air flow about this model. From these tests are drawn inferences as to the cause and cure of aerodynamic wing vibrations. Part II derives stability criteria for wing vibrations in pitch and roll, and gives design rules to obviate instability. Part III shows how to design spars to flex equally under a given wing loading and thereby economically minimize the twisting in pitch that permits cumulative flutter.

Resonant flutter is not likely to ensue from turbulence of air flow alone past wings and tail planes in usual flying conditions. To be flutterproof a wing must be void of reversible autorotation and not have its centroid far aft of its pitching axis, i.e., axis of pitching motion. Danger of flutter is minimized by so proportioning the wing's torsional resisting moment to the air pitching moment at high-speed angles that the torsional flexure is always small.

Report No. 288. Pressure Distribution Over a Rectangular Monoplane Wing Model Up to 90° Angle of Attack, by Montgomery Knight and Oscar Loeser, Jr. 19 pages, illustrations, quarto, price ten cents.

The pressure distribution tests herein described, covering angles of attack up to 90°, were made on a rectangular monoplane wing model in the atmospheric wind tunnel of the Langley Memorial Aeronautical Laboratory.

These tests indicate that a rectangular wing, by reason of its large tip loads, is uneconomical aerodynamically and structurally, has pronounced lateral instability above maximum lift, and is not adaptable to accurate calculation based on the classical wing theory.

ICE ENGINEERING. By Howard T. Barnes, F.R.S. 364 pages, illustrations, 8vo. Montreal, Renouf Publishing Company, 1928. Price, $5.

In all hydraulic projects located in climates where freezing temperatures occur, the careful consideration of ice formation is of paramount importance. Some twenty odd years ago, the author analyzed the phenomena of ice-formations in their various phases in his rarely interesting treatise "Ice Formation" (Wiley & Sons, N. Y., 1906). Therein he described some of the serious obstacles to the operation of hydraulic power plants incident to such accumulations of ice as well as their frequently destructive effects upon nearly all types of hydraulic works. The author's investigations in recent years have added materially to our knowledge of rational methods, of meeting these baleful effects of ice formation in the operation of hydraulic power projects and these advances he chronicles in his new book which deals specifically with the engineering aspects of the ice problem.

Almost one-half of the book deals with the physics of ice-formation which is considered in its most modern aspects as, for example an account of the colloidal character of the ice particles which flocculate and finally form a true ice crystal. Again there is an analytical discussion on the rate of growth of ice with reference to the work of Dr. S. Tetsu Tamura and that of Prof. L. V. King of McGill University and others. The important forms known as anchor ice and frazil ice are given a lengthy consideration at the end of this part of the subject.

The applications of remedial measures against prejudicial ice formation occupy another division of the work. Among these are considered, steam, thermit and other chemicals. The author's investigations in the use of thermit and its application in the removal of ice jams are a classic which has received wide publicity in technical and popular science journals. Another important branch, ice navigation and ice breaking, receives an equally thorough survey. Among other topics of practical value are, conservation of heat in lakes and rivers for ice prevention, glaciers and icebergs and another application of thermit for the destruction of icebergs. A copious classified bibliography is included at the end of the work.

The work contains a very large amount of statistical and, where possible, of analytical information of great value to the hydraulician operating in cold climates as well as of deep interest to the serious general reader.

LUCIEN E. PICOLET.

THE FALLS OF NIAGARA. By Glenn G. Forrester. 155 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1928. Price, $2.50.

The United States is favored by having within its borders an unusually large number of great natural scenes. Niagara, the Yellowstone, the Yosemite, the petrified forest, and the Grand Canyon, the last considered by many the most impressive sight in the world. Of course, in such a vast area as our country covers, one would expect much variety in scenery, but the geologic history of North America has been especially fertile in producing high contrasts and profound modifications.

The volume in hand is an instructive account of the present state of the great cataract, of its development and the principal incidents in its career as far as the testimony of the rocks can show. There is appended a guide to the falls and its environment. The history of the cataract involves the story of the glacier period and evidences of its actions. Decidedly different geographical conditions in earlier periods have been found by geologists which are set forth in careful description and by numerous maps. Many excellent plates are also included. The book is entertainingly written. The future of the cataract is a matter of interest. There is no doubt that it has worked its way back for a great distance, by corrosion of the rocks, and that it is still steadily retreating, but this movement will not interfere with the attractiveness of the scene for many centuries. A serious danger, however, threatens from the economic side. The water-power that it represents has already resulted in the diversion of one third of the supply and in time the diversion may be such that the Falls will be on exhibition only on Sundays and holidays. An admirer of nature will be inclined to say with Hector:

> "May I be dead before that dreadful day
> Presses with a load of monumental clay."

HENRY LEFFMANN.

THE PHYSICS OF CRYSTALS. By Abram F. Joffé, Ph.D., D.Sc., D.Eng., LL.D., Director, Roentgen Institute; Director, Physical Technical Institute. Edited by Leonard B. Loeb, Associate Professor of Physics in the University of California. xi–198 pages, 61 figures, 8vo, cloth. First Edition, New York, McGraw-Hill Book Company, Inc. Price, $3.

Gilbert N. Lewis, in his introduction to this volume, speaks thus: "In late years the great rush to the new gold fields of physics has caused a temporary abandonment of the well worked but still rich leads of classical physics. The author has returned to one of the most old-fashioned of physical themes in his study of the mechanical and electrical properties of solids, and in this rejuvenation of an ancient problem with the aid of all modern resources of theory and practice, our admiration is divided between the ingenuity of the methods devised and the technical skill shown in their application."

As the author states in the preface, this book represents the organization into a consistent system of the results of a number of investigations on the physics of crystals which the author and his collaborators have been carrying on for the last twenty-five years. The subject matter covers a limited portion of the field of elastic and electrical properties of solids, particularly crystals.

The first six lectures deal with the mechanical properties and behavior of crystals while the remaining eleven are concerned with the electrical behavior of both single crystals and solid dielectrics. The introductory lecture outlines the electrical theory of crystal lattices with a view to effecting the visualization of a mechanical model. This is followed by both a general and a mathematical discussion of equilibrium in a crystal lattice. A systematic series of experiments upon the elastic after-effect have shown that all such disturbing phenomena are a result of irregularities existing in the crystal. X-rays have been used in the study of the elastic limit of crystals and the mechanism of their plastic deformation. A carefully conducted series of experiments has accounted for the anomaly existing between the calculated strengths of crystals and those observed under the application of mechanical stress.

The lecture upon the conduction of electricity through crystals demonstrates once more the validity of Ohm's law for the flow of electric current. A close study of the specific conductivity of crystals emphasized further the necessity of working with a pure material. Careful experiments on the electrolysis of crystals show that for a certain quantity of electric energy passed there is transported a corresponding number of ions possessing a total charge equal to the amount of electricity passed. Special studies have been made on the electrical behavior of both quartz and calcite. Among other subjects the author has made a study of electronic conductivity in crystals. Such a conductivity is influenced by the application of wave energy from some external source. Calculations on the amount of energy necessary to displace an electron from its atom and the crystal lattice also have been made. The problem of dielectric losses and the breakdown of dielectrics by heat and by ionization are treated mathematically and many examples of seeming anomalous behavior are explained Much interesting information has been gained through the study of the dielectric strength of thin strips of material. There is every indication that breakdown is caused by the enormous mechanical pressure exerted by the two electrodes due to their induced attraction for each other. Important technical applications of these strong electric fields which now may be obtained without breakdown of dielectrics are cited by the author. Some of these are: (1) construction of condensers of a very high capacity and a high breakdown potential; (2) the use of such condensers as storage batteries giving a high degree of concentration of energy; (3) these attractive forces could be used to replace electromagnets and relays; (4) the ionization by collision by such fields might be used as an effective amplifying device.

Dr. Joffé is to be congratulated upon the manner in which he has arranged and presented the facts with their corresponding theoretical considerations. Moreover, great credit is due to Prof. Leonard B. Loeb for his able work in editing all this material. Such a book should be of value to the physicist, chemist, and metallurgist in particular. T. K. CLEVELAND.

MECHANOCHEMISTRY AND THE COLLOID MILL. By Pierce M. Travis, President, Travis Colloid Research Co., Inc. 191 pages, 17 illustrations, cloth, 8vo. New York, The Chemical Catalog Company, Inc., 1928. Price, $4.

Such a book as this may be considered interesting even from the chronological standpoint. It is truly representative of the progress made in the last

two decades in the organization of a vast quantity of empirical knowledge arising from a study of colloids. This type of treatise might be viewed as a step in advance of the colloid laboratory manual for it deals with the application of general, colloid-chemistry principles to the practical arts.

"Mechanochemistry" is the name given by the author to the process of mechanical dispersion involving the principles of physical chemistry. The subject matter includes, first, a practical discussion of the relationships existing between matter in various states, i.e., degrees of dispersion and its corresponding physical and physico-chemical properties; second, the application of such knowledge toward the successful dispersion of materials and third, the various types of mechanical apparatus used to accomplish such dispersion. Some idea as to the applications of these colloid mills may be obtained when it is found that they are used for the emulsification of vegetable, animal and mineral oils, resins and waxes, the manufacture of paints and enamels, improvement of milk in regard to digestibility and the making of ice cream, extraction of oils, fats, resins and juices from vegetable or animal tissues, purification of organic chemicals, liquids and solids, intimate mixing of foodstuffs as in the preparation of sauces and salad dressings, dispersion of solids such as mica, certain oxides, fine clays, various dyes and other such materials.

The author has appropriately incorporated a chapter on the elementary structure of matter which will aid greatly toward the visualizing of particles in the colloidal state. Proper stress has been laid upon the part played by electrical charges and hydrogen ion concentration. One of the more important chapters deals with the protective action of colloids in dispersions which is exemplified still further by chapters on the dispersion of solids and liquids in gas, of solids in liquids and the theory of emulsions and emulsification, i.e., the dispersion of liquids in liquids. The construction and operation of various colloid mills are clearly described and their respective utilities critically considered. The book is concluded by a brief chapter on laboratory methods and physical testing of properties.

On the whole, the book is very well written and what might seem to be redundancy in various cases is merely reiteration employed by the author for the purpose of emphasis. There seems to be an incorrect and contradictory statement made at the top of page 70. In referring to the concentrations of potassium, barium and aluminum ions required to agglomerate particles of arsenic trisulfide to the same degree the ratio is given as 1 : 20 : 1000 whereas it should be reversed. It is probable that Fig. 16 would appear more natural if inverted.

There is no doubt but what "Mechanochemistry and the Colloid Mill" will be of great value to the chemical engineer. Moreover, it should prove its worth as a reference work in the libraries of consulting chemists and engineers and something which would pay every student of chemical engineering to read.

T. K. CLEVELAND.

MATTER, ELECTRICITY, ENERGY. By Walter Gerlach, o. ö. Professor, University of Tübingen. Translated from the second German edition by Francis J. Fuchs, Ph.D., St. John's College, Brooklyn, N. Y. xii–427 pages, 119 figures, cloth, 8vo. New York, D. Van Nostrand Company, Inc., 1928. Price, $6.

To the biologist, geologist, physicist, chemist, engineer, technologist and others whose work or interest involves an intimate relationship with some branch of scientific knowledge there occasionally arises a desire for a closer acquaintance with the fundamental concepts and basic theories seeking to explain the why and the wherefore of various natural phenomena. Those, whose occupational pursuits have not necessitated a knowledge of physics deeper than that furnished by the prescribed general courses in college are vaguely aware that many new and significant facts concerning matter and energy have been discovered and as a result of these findings the older theories have been discarded or altered to a radical extent. This book is recommended to those who wish to acquaint themselves to a greater or less degree with the more recent discoveries, the lines of research pursued and the trend of contemporary thought in the realm of physics. This book has been written for those who possess at least a general knowledge of physics and the concepts implied by the simpler terms. It was not compiled with the intention of popularizing the subject in the mind of the layman.

The author does not attempt to treat exhaustively each subject but only to furnish a general, yet very comprehensive survey of the whole field. The first edition appeared in Germany in 1923 and met with an extremely friendly reception. In many cases professors adopted the book for the graduate students in seminar work. In the second edition (1926) the author has attempted to fill in some of the gaps and make its scope that much broader. The title would lead the reader to expect a discourse on anything and everything under the sun. However, a glance through the table of contents will indicate that the book deals with the atom, its structure and the relations between that structure and the accompanying energy phenomena.

Chapter one on General Atomistics serves as a fitting introduction to that which follows. Attention is directed toward the changing definition of an element which has had to be revised due to the discovery of the radioactive transformation of matter. Elements no longer are held to be indestructible. Examples are given showing the limitations of chemical methods in bringing about the discovery of new elements and its replacement by the method of X-ray spectral analysis. The chapter is concluded by some observations upon the uncertainty of the mechanical explanation of atomic and inter-atomic processes and the many perplexing problems involved in the use and interpretation of the quantum theory. The subject of isotopy is discussed very thoroughly particular attention being paid to latest improved methods of isotope determination and their subsequent separation. In addition the chapter contains a theoretical discussion on the relation between the line and band spectra of an element and its isotopes.

Like a weed the existence of atomic rays in the wrong place has proven a nuisance. These latter are responsible for the blackening of the interior walls of incandescent light bulbs. However, in chapter three, the author relates how the physicists have utilized atomic rays in the determination of molecular thermal

velocities, the mean free paths of molecules and the experimental confirmation of the magnetic moment of individual atoms.

The study of molecular dipoles leads into a field of vast experimental possibilities. What results have been obtained in preliminary research seem to indicate that such physical properties as dielectric constant, dispersion of electric waves, viscosity, electric double refraction are inextricably linked with the existence of molecular dipoles.

Probably no phenomenon has furnished so much information concerning the ultimate structure of molecular nuclei than that of their disruption by alpha particles. A close study of these effects has led to the concept of the nuclei being constructed from "bricks" which represent hydrogen and helium atoms.

Probably chapters six and seven contain material possessing greatest fundamental interest, i.e., the fundamental unit of electricity and the relation between this unit and the mass of that particle of matter bearing it. It is noteworthy that in this phase of physics more than in any other has such a wealth of experimental evidence been available for application to the numerous controversies. A discussion of the "magneton" logically follows the two foregoing chapters. The assumption is made that each atom becomes an individual magnet by virtue of charged electrons rotating around it. It is noteworthy that a theoretical treatment of the subject indicates the magnetic moment of the atom to be dependent upon only the specific charge and Planck's constant.

An extremely interesting phenomenon is that of superconductivity as evidenced by some metals at very low temperatures. A plausible explanation of this anomalous behavior is still lacking. Up to the present, studies upon crystal conduction have disclosed many remarkable facts. A comparison between the ionic conductivity of crystals and the electronic conductivity of metals emphasizes their respective behavior towards incident light, the former being transparent while the latter reflects.

The next two hundred pages—equal to half the book—are concerned with what is probably the most important phase of physical science, namely, spectra and spectra analysis. Naturally the subject is introduced by a discussion of the quantum theory and an explanation in general terms of the mechanism of radiation by the atoms. Hydrogen, possessing the least complicated structure of all the elements, has been studied intensively in respect to its spectrum. The agreement between the observed wave-lengths of the spectrum lines and the lengths calculated by a simple formula is truly amazing. The author has set forth clearly the experimental evidence indicating that the Roentgen rays (X-rays) possess the nature of electro-magnetic pulsations. The problem of measuring the intensity of X-ray spectra has proved similar to one involved in finding a container for an universal solvent. X-rays, coming in contact with the measuring apparatus often excited a second series which would lead to erroneous results. A brief outline of the correlations existing between the spectral emissions of an atom and its position in the periodic system serves to emphasize further the belief that we are on the right track in our postulations regarding atomic structure.

An idea how the Bohr theory could serve to stimulate experimental investigation on emission and absorption phenomena taking place within an atom will be gained in a perusal of chapter sixteen. The chapter following deals with specific cases of resonance and dispersion as effected by X-radiation, and includes

a discussion of the Compton Effect in that connection. It is interesting to learn that practically all the gaps long existent in the electro-magnetic spectrum have been filled in, at last. The first portion recognized, that of visible rays, soon was extended in either direction; to the infra-red in the region of longer wave-lengths and the ultra-violet in the shorter. The discovery of the Hertzian waves (radio waves) and the Roentgen rays (X-rays) occurred at about the same time. As a result two gaps existed, one between the infra-red and the longer radio waves and the other between the ultra-violet and the shorter X-rays. Discovery of the gamma ray shorter still than the X-ray extended the spectrum still further into the region of shorter wave-lengths. Since this book was written discoveries by Millikan indicate the presence of an extremely short and highly penetrative ray (cosmic ray). The gap in the longer wave-lengths has been narrowed by an approach from both directions, namely, the production of very short radio waves and extra long infra-red or heat waves. The gap in the shorter wave-lengths has been eliminated chiefly by investigations of the longer X-rays. It will be conceded that a more extended study of the rays in these hitherto little known regions will throw considerable light upon the state and structure of matter since it is generally recognized that the waves below the ultra-violet region are produced by electrons; those in the ultra-violet and visible by similar but less energized particles while those in the infra-red and beyond by atoms, molecules and aggregates of molecules.

The photo-electric effect which is the ability of certain substances to emit negatively charged electrons when illuminated is discussed in regard to theory and, its application by means of the photo-electric cell to the examination of photographs of band and line spectra. Many readers will be more aware of its application in the realm of television and telephotography. A short chapter on spectrophotometric problems points out the troubles encountered in the measurement of the energy distribution in the spectrum produced by a hot body. Sufficient work has been done upon the reflection of infra-red rays from crystals to show that the selective reflection exhibited may be attributed to the presence of certain molecular groups or radicals composing the crystal. On the other hand application of X-rays also has been made for the elucidation of crystal structure. By means of X-rays it is possible to depict just how the crystal is constructed by indicating the relative positions of the atoms.

With the introduction of the quantum theory into photochemistry A. Einstein has taken a long step toward placing photochemical reactions upon a quantitative basis particularly by showing that to produce a definite chemical change a definite amount of energy always must be absorbed. In a discussion of luminescence in chemical reactions the author points out that certain visible radiations are emitted by the atom without concurrent thermal excitation. Attempts have been made to account for this phenomenon theoretically by means of the quantum theory. A further application of the quantum theory is to be found in the calculation of electron-affinities; i.e., the energy involved when an electron is separated from an atom during ionization. The chapter on chemical reactions by means of electronic impact is relatively short and contains none of the later work along this line carried out by such persons as S. C. Lind, W. D. Coolidge and others.

In the chapter on photochemical catalysis the sensitization of photographic

plates is discussed and a possible mechanism for the action of the sensitizing substance submitted. Under "Radiation Measurements" the author summarizes the work which has been done on the determination of Stefan-Boltzmann and Planck constants through the medium of black-body radiation. Mention is also made of the very delicate experiments performed to establish the existence of radiation pressure. There is no doubt but the final chapter on "Atomism and Macrocosmos" possesses great general interest. In it is summarized as a review that available physical knowledge which might prove helpful in astral-analysis. This is followed by a list of the essential facts of astronomy and of experimental astro-physics. The chapter ends with a most interesting exposition on the application of present physical knowledge in the elucidation of star characteristics, such as temperature, size, distance and elementary composition.

Naturally in such a work as this typographical errors are bound to creep in and are not worth the mention. However, in one or two instances, there has appeared an error or omission to which attention might be called. On page 128, Fig. 28, the positions of the two photographs of atomic rays should be reversed in order to agree with the subtitle. In the third column of the table on page 168 the figures are correct but the decimal point seems to be misplaced, judging from the column heading. In Fig. 80, page 329, the designation of the abscissas of the curve has been omitted, while on page 372 there was a failure to state whether the temperature of a blast flame is ° C. or ° F. In speaking of the reduction of oleic acid the statement is made that it was "hydrated whereas "hydrogenated" is the correct word. The word "undubitably" could well be changed to "indubitably" and the retention of the German word "zeolith" seems unnecessary since we have the corresponding English word "zeolite."

Anyone who has attempted to translate a scientific treatise from one language to another realizes that to be successful, the translator also must be well acquainted with the subject involved. It is evident that Dr. Fuchs possesses all the necessary attributes for one cannot help being impressed by the almost unfailing use of the correct shades of meaning. The translator as well as the author is to be congratulated for this English edition, the production of which is an art within itself.

T. K. CLEVELAND.

ORGANIC CHEMISTRY. A brief introductory course. By James Boyant Conant. 291 pages, illustrations, 8vo. New York, The Macmillan Company, 1928.

This book differs notably from the ordinary elementary manuals of organic chemistry. It treats the subject in what may be called a topical manner. The text proper begins with a description of the alcohols, taking the common one as being of so much practical importance as to be suitable for an introductory study. The method of finding its molecular weight is presented (that is, arithmetically) and the formula deduced therefrom. For the procedures, references are made to standard manuals. From the demonstration of the calculation of the formula, the question of isomerism and the necessity for structural formulas are developed and the theory of linkages briefly treated. Much space is given to the writing of structural formulas. The section on alcohols is followed by one on the immediate derivatives, and the text then takes up petroleum. In this manner the discussion proceeds until all the great groups of organic chemistry are treated. There is a

very large amount of modern chemistry in the book, very carefully and accurately set forth. Whether the general method will prove entirely satisfactory in practice cannot be stated as yet. The sub-title, "A Brief Introductory Course," challenges argument, but only wide use will determine whether the book has real advantage over the more formal and carefully systematized manuals generally in vogue.

A commendable feature is the stress laid upon interpreting organic formulas, on the tri-dimensional system. This should be frequently used by both teacher and pupil. There is far too little use of models in the teaching of organic chemistry. The presentation of the theories of the composition and relations of organic bodies as set forth in this book contrasted with similar data in inorganic manuals shows how much two branches of descriptive chemistry are apart in their pedagogic phases.

In a future edition, more prominence should be given to the use of the name "methanol" for methyl alcohol, in pursuance of the wish of sanitarians to eliminate the term "alcohol" from the name of the substance. It also seems to the reviewer that it is an error to speak of racemic acid as a form of tartaric acid. Whether this acid is considered theoretically as a "racemic mixture" or a "racemic compound" it is, after all only the two active tartaric acids in association. The older chemists will be rather astonished to learn that in modern parlance the letters "*d*" and "*l*" applied to carbohydrates, do not refer to the direction in which polarized light is turned, but to the spatial relations of the groups. Hence levulose though levorotatory is termed *d*-fructose. Truly the world moves. On page 128 it is stated that chloroform for anesthesia must be pure, but the U. S. P. requirement is that it should contain not less than 0.6 per cent. of alcohol. This greatly retards decomposition.

HENRY LEFFMANN.

"THE NEW REFORMATION" (FROM PHYSICAL TO SPIRITUAL REALITIES). By Michael Pupin, of Columbia University. XVII–273, pages, 12mo., cloth, New York, Charles Scribner's Sons, 1928. Price, $2.50.

If Dr. Pupin were an athlete, he would have what Jack Dempsey in boxing and Jean Borotra in tennis possess—that is, "colorfulness." As a scientist, this power of making a popular appeal may be at once an asset and a liability to him. He undoubtedly gets his fine personality across to his readers. But does he, at the same time, lose any of his splendid prestige as a hard-headed man of science? We are inclined to think that he does not.

Our first impression of this book was that it represented another structure, similar to those reared by Henry Gordon Drummond in his "Natural Laws in the Spiritual World," Dr. W. W. Keen on "Evolution and Christianity," and by Joseph Le Conte (1826–1902) the brilliant geologist in his "Religion and Science" and "Evolution and Its Relation to Religious Thought" (many other scientists have done the same) and employing scientific principles upon which to compose statements of religious faith.

Dr. Pupin does indeed do this but he has the advantage of the greater store of information offered by the scientific achievements of recent years and he has the rare gift of combining "close thinking" with a high degree of human interest.

We would not disparage the arguments of the other authors mentioned when we state that, in our belief, Pupin has not merely produced "just another book"

but has given us one that for a long time to come will hold a commanding place in the field of "Intrascience" (the science within science); and will be read more than once by the person competent to perceive its significance.

Every scientist, without a doubt, has in his own mind a fairly definite idea of what is meant by the "scientific method," although the verbal expression of the idea might vary from that given by others. For example, Baker Brownell (a philosopher, not a scientist) considers science to be the product of "sensation and reason," whereas Pupin defines it as "observation, experiment and calculation." The latter is, of course, the more careful definition.

Pupin goes further and endeavors to disclose the inner spirit of true science when he writes:

"Humility was not always a cardinal virtue of religious reformers, but it was such a virtue of men with a truly scientific mental attitude. In the presence of God's eternal truth they humbly bow down and cheerfully accept any place which that truth assigns to them."

Dr. Pupin's book is unusual in many ways. He has no table of contents. He writes a Prologue and declares the seven sections which follow to be not chapters but "narratives." These are the titles:

"I. The Awakening of Scientific Individualism;
II. The Physical Reality of Matter in Motion;
III. The Physical Reality of Electricity in Motion;
IV. The Physical Reality of Electrical Radiation;
V. Granular Structure of Electricity and of Radiation;
VI. From Chaos to Cosmos;
VII. Creative Co-ordination."

The author outlines his purpose thus:

"It is hoped that by strengthening our understanding of the physical realities the narratives will reform our mental attitude and make it better prepared for the recognition of the truth that physical and spiritual realities are the fruit of the same tree of knowledge, which was nurtured by the soil of human experience."

Emphasis is laid upon the granular structure of electricity and radiation and the thought is advanced that living cells in organic life and human beings in society might similarly be regarded as "granules."

The Columbia University Professor presents a new concept which he names "Creative Co-ordination;" drawing the picture from a review of Carnot's law of action of the moving power of heat. Pupin writes:

"Just as the steam-engine co-ordinates the non-co-ordinated activity of the erratic molecules of the hot steam, so the galvanic cell is a co-ordinator of the non-co-ordinated chemical activity of the atoms and molecules of the metals and fluids in the cell."

We quote further:

"The physical life of man is the highest product of this creative co-ordination; to transform the life of humanity into a cosmos, a life of simple law and beautiful order, is the highest mission of human life in its broadest aspect. Can it perform this mission by the revelation of physical realities only? No, it cannot; it must search for other realities which are today outside of the domain of physical science."

Then the author applies the concept to organic life where he finds the living cell is the "creative co-ordinator:" and then to the world of consciousness in which he suggests that "Love, according to Christ," is the most powerful of these "co-ordinating forces."

"Just as the cosmic processes of creative co-ordination guide the evolution of the external material world," he asserts, "so creative co-ordination also guides the evolution of the internal world of the human soul, the destiny of human life. This is my message from science."

These passages also deserve especial attention:

"This (Newton's deductions) is the revelation which conveyed to man the joyful message that nature in every part of the universe, as revealed by the motions of heavenly bodies, is intelligible, and that she employed the same simple language and logic when she spoke to Archimedes in the baths of Syracuse, to young Galileo in the Cathedral of Pisa, and to Tycho Brahe and Kepler, when, with a watchful gaze, they recorded and scrutinized the paths of the planetary wanderers in the distant depths of heaven, an ideally simple message describing an ideally simple material universe."

"The mental attitude of man is often controlled by countless tiny motions; it is as immovable as the stump of an ancient oak which grips the soil with countless tiny roots. Nothing illustrates better the inertia of the mental attitude of Christian theology and that of science."

Then there is an Epilogue which many would cite as one of the best sermons ever written.

JOHN W. STOCKWELL.

PUBLICATIONS RECEIVED.

The Electrical Conductivity of the Atmosphere and Its Causes, by Victor F. Hess, Ph.D. 204 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1928, price $4.00.

The Fundamentals of Human Motivation, by Leonard T. Troland, Ph.D. 521 pages, 8vo. New York, D. Van Nostrand Company, Inc., 1928, price $5.00.

The Falls of Niagara, by Glenn C. Forrester. 155 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1928, price $2.50.

Radio. A Study of First Principles for Schools, Evening Classes and Home Study, by Elmer E. Burns. 255 pages, illustrations, 12mo. New York, D. Van Nostrand Company, Inc., 1928, price $2.00.

Practical Television, by E. T. Larner. 175 pages, illustrations, plates, 8vo. New York, D. Van Nostrand Company, Inc., 1928, price $3.75.

Organic Chemistry. A Brief Introductory Course, by James Bryant Conant. 291 pages, diagrams, 8vo. New York, The Macmillan Company, 1928.

Balistique Intérieure Théorique et Tables Numeriques, by G. Sugot. 130 pages, diagrams, tables, 8vo. Paris, Gauthier-Villars & Cie, 1928, price 40 fr.

Balistique Extérieure Théorique, by G. Sugot. Pages 828 to 920, illustrations, 8vo. Paris, Gauthier-Villars & Cie, 1928, price 25 fr.

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Ice Engineering, by Howard T. Barnes. 364 pages, illustrations, 8vo. Montreal, Renouf Publishing Co., 1928, price $5.00.

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CURRENT TOPICS.

Differential Intensity Sensitivity of the Ear for Pure Tones. R. R. RIESZ. (*Phys. Rev.*, May, 1928.) No one doubts the technical value of telephone engineering but in pure physics it plays an important rôle in preventing the disappearance from journals of articles dealing with sound. The communication engineer needs to know the smallest change in intensity that the human ear can detect. "This information is also of interest to physicists when considering the ear as a physical instrument, to psychologists in formulating relationships between exciting physical stimulus and the resulting sensation and to otologists in the study of normal and abnormal hearing." In 1923 the *Physical Review* published Knudsen's results on this subject which have constituted the best available source of information up to the present but they did not cover the entire range of intensities and frequencies for which the ear is sensitive. This investigation embraces practically the complete range.

The quantity measured in these experiments is the ratio of the smallest possible increment in the intensity of sound that the ear can perceive to the total intensity of the sound. Here this fraction will be designated "differential sensitivity" though it is called also Weber's constant, Weber-Fechner ratio, and intensity sensibility. The differential sensitivity of twelve normal observers was studied for frequencies ranging from 35 to 10,000 cycles per sec. and for intensities from the threshold of audition to the threshold of feeling. The changes of intensity studied were obtained by sending through a special telephone receiver two alternating currents simultaneously, their frequencies being so nearly alike that beats were produced, while the two resulting tones differed too little in pitch to complicate the observations. A preliminary study showed that the differential sensitivity depends upon the interval of time between the production of the two sounds whose intensities are to be compared. For 1,000 cycles per sec. the differential sensitivity was a minimum in the vicinity of 3 beats per sec. This number of beats was therefore selected as the normal one for use.

Two vacuum tube oscillators produced alternating currents of any specified frequency. The two currents passed through voltage attenuators, then through an electric filter to remove harmonics and thence to the telephone receiver of special construction. One

oscillator was set at some frequency and the other at such a frequency as to give three beats per sec. One of the currents from an attenuator was fixed at a certain voltage and the voltage from the other varied until beats became just audible. From the theory of beats and the relation between impressed voltage and intensity it is possible to calculate the differential sensitivity for the frequency and intensity in this case. "Complete series of measurements were made on twelve male observers at frequencies of 35, 70, 200, 1,000, 4,000, 7,000, and 10,000 cycles per second and at intensities from weak tones near the threshold of audition to very loud tones near the threshold of feeling." The curves representing the results show "that at any given frequency the differential sensitivity approaches a constant value for high intensities but increases rapidly as the intensity is reduced toward the auditory threshold." No matter what the frequency the differential sensitivity is about the same for all intensities 1,000,000 or more times as great as the minimum intensity affecting the ear. If tones of different intensity are investigated it is seen that in all cases the differential sensitivity is least for about 2,500 cycles per sec., that is, for this frequency the ear can detect the least change of intensity. "At 1,300 cycles per second the ear can distinguish the greatest number of tones as being of different intensity, that number being 370." G. F. S.

Experiments on the Diffraction of Cathode Rays. G. P. THOMSON. (*Proc. Roy. Soc.*, A 778.) According to de Broglie's theory of mechanics a particle in motion acts as a group of waves whose velocity and wave-length can be calculated from the mass and velocity of the particle. This velocity of the waves is greater than the velocity of light, but the Theory of Relativity is not thereby violated because the waves are geometrical conceptions and do not carry energy. "The consequences of this theory have been worked out by de Broglie, Schroedinger and others and applied to problems in spectroscopy where they have provided the solution of several outstanding difficulties left by the older theory of orbits. In view, however, of the extremely fundamental nature of the theory it is highly desirable that it should rest on more direct evidence, and, in particular, that it should be shown capable of predicting as well as of merely explaining." The work of Davisson on the reflection of electrons from the surface of crystals is of great importance in this connection. ("Are Electrons Waves?" Davisson. JOURNAL OF THE FRANKLIN INSTITUTE, May, 1928.) In the present paper the author recounts his quest for an effect of crystals upon electrons that shall resemble the diffraction of X-rays by crystals.

For electrons that have fallen through a potential difference of 25,000 volts to gain their velocity the length of the equivalent waves is about 0.75×10^{-9} cm. "This is of the order of that of hard X-rays and the waves associated with electrons of this energy should behave in many respects like hard X-rays. In particular the electrons should show diffraction effects when passed through a crystal identical with those shown by X-rays of the same wave-length. It is, perhaps, hardly necessary to say that this does not mean that the two are indistinguishable. Unlike X-rays the electrons are deflected by electric and magnetic fields. They carry a charge, and for equal wave-lengths, have much less energy and less penetrating power." In the experiment a beam of cathode rays, that is, of electrons, fell through voltages ranging from 12,000 to 61,200 and passed through a tube of fine bore into a chamber maintained at a low vacuum. The application of a magnetic field showed the beam to be nearly homogeneous. In the chamber it fell at normal incidence upon thin films made up of crystals and, emerging, was received by a photographic plate 32.5 cm. behind the film. If the film consists of crystals with random arrangement one type of pattern should be imprinted on the plate. If, on the other hand, there is a somewhat orderly arrangement of the crystals a modified pattern will appear. Both cases were actually observed. The main difficulty encountered was to get films so thin that the electron was scattered only once in traversing it. Of aluminium "the films used were the thinnest foil etched down by floating in caustic potash until they were transparent." The maximum thickness for good results was about 10^{-5} cm. Gold films were made thin by aqua regia and a film of celluloid 5×10^{-6} cm. in thickness also was used. Reproductions of the patterns obtained are given. "In all cases the general effect is that of a series of concentric rings round the spot made by the undeflected beam. In some cases these rings are uniform round the circumference, in others the intensity is more or less concentrated in a series of spots on the circumference." The patterns are much like those produced by X-rays in the "powder" method. The dimensions of the rings should vary with the velocity of the electrons, if they are due to diffraction. In the case of both aluminium and gold the diameters of the rings changed as the voltage was varied and, more than that, followed in their changes a relation derived from de Broglie's theory. Moreover when the side of a unit cube of these metals is computed from the data of the experiment it comes out in both instances within about one per cent. of the value obtained from the diffraction of X-rays.

These experiments on diffraction following as they do those of

Davisson on reflection go far to show that there is a real physical basis for the wave theory of mechanics. G. F. S.

The Specific Heats of Ferromagnetic Substances. L. F. BATES. (*Proc. Roy. Soc.*, A 778.) Pierre Weiss, now of the University of Strasbourg, on the basis of his theory of the internal molecular field predicted that ferromagnetic substances should show discontinuities in their specific heats near the temperatures at which they change into paramagnetic substances. He and his collaborators conducted experiments on the specific heats of nickel, iron and magnetite that afforded at least partial confirmation of the prediction. In Great Britain Sucksmith and Porter examined nickel and Heusler alloy. Their results were not in agreement with Weiss' theory because the change in the specific heat was not limited to the temperature at which the magnetic properties practically disappeared but was spread out over a considerable range of temperature. The existence of a group of manganese compounds, the phosphide, arsenide, antimonide and bismuthide, magnetic in character and having critical points at 26°, 45°, 330°, and 380° respectively renders it possible to institute a fresh investigation with none of the difficulties due to the employment of high temperatures. MnAs was prepared according to the directions of its discoverers, Hilpert and Dieckmann. The relation of its magnetic properties to temperature was examined. "The substance ceases to be ferromagnetic in the neighborhood of 45° C. If, however, the temperature is reduced after the specimen has been rendered paramagnetic, it is seen that the induction changes but slightly until a temperature between 33.5° and 34° is reached, when the substance rapidly regains its ferromagnetic properties."

The calorimetric method consisted in supplying heat slowly to the powdered arsenide by an electric current flowing through No. 42 manganin wire, the temperature being read at the same time from the resistance of another coil in the powder. 8912 seconds were needed to raise the temperature from 25.5° to 53.8° C. "The specific heat rises slowly from a value of 0.122 at 28° C., to a value of 0.14 at 36° C., then rises with increasing rapidity to a value of about 0.8 in the neighborhood of 42° C., then falls rapidly to a value of 0.13 at 45° C., and thence to a slightly defined minimum value of 0.10 at 46.5° C., after which it slowly rises with increase of temperature."

The relation between the temperature of the arsenide and its induction in a strong magnetic field was studied. When a curve is plotted connecting temperature with rate of change of induction with temperature it is found to have a close resemblance to the

specific heat-temperature curve. The maxima of the two curves occur at the same temperature.

The author calculates that the addition of 1.79 calories per gram is required to transform the ferromagnetic arsenide into its paramagnetic form. The results of the investigation seem to confirm Weiss' theory. G. F. S.

From the Physical Laboratory of the University of Utrecht comes an interesting determination of the rate of production of quanta of light in a sodium flame. It is found that each atom emits in a second 250 quanta when the temperature is 1,970° C. (*Ann. d. Physik*, No. 7, 1928.) G. F. S.

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